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CONTROLLERS
FOR ELECTRIC MOTORS

A Treatise on the Modern Industrial Controller,
together with
Typical Applications to the Industries

BY

HENRY DUVALL JAMES, B.S., M.E.
Fellow, American Institute of Electrical Engineers
Past President Engineers' Society of Western Pennsylvania

SECOND EDITION—COMPLETELY REVISED AND ENLARGED

444 ILLUSTRATIONS

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PREFACE

THE material in the first edition of this book appeared as a series of articles in the Electric Journal during 1917 and 1918 and was issued in book form in 1919. Since then a part of this text has been rewritten and considerable material added.

The object of this book is to bring together in one volume sufficient material on control to give a good general idea of its designs and operation for the use of Technical Students, Operating Engineers, purchasers and users of electrical apparatus. The illustrations have been selected for the purpose of giving a good idea of the control in general use and to assist in understanding the text. No attempt has been made to have these illustrations represent all types of commercial apparatus. Additional illustrations can be obtained from Trade Publications.

Some elementary chapters have been included for the benefit of persons who have not had a considerable experience with control apparatus. The various applications have been selected for the purpose of showing the different systems of control and some of the more important controller problems. Most of the diagrams are of an elementary nature, only a few complete diagrams having been included. These latter will give a practical idea of commercial diagrams. When it is necessary to repair or adjust a controller, a diagram and instructions should be obtained from the maker. The material in this book should assist in understanding a controller but must be supplemented by exact information covering the particular design under consideration.

In the application sections, the processes and methods of operation are described in some detail, as this information is always essential to a proper understanding of the control. Many controller troubles arise from the lack of complete information of this nature.

I wish to express my appreciation of the assistance I received from the Engineers associated with me and to thank the various manufacturers who so kindly furnished material for the illustrations. In particular I wish to mention the assistance I received from the Editorial Staff of the Electric Journal who checked most of the material and made many valued suggestions.

H. D. JAMES.

PITTSBURGH, PENNA.
June, 1926.

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CONTROLLERS FOR ELECTRIC MOTORS

CHAPTER I

INTRODUCTION—FUNCTION OF CONTROL

Functions of Control—Classification of controllers (1) as to means of acceleration, (2) as to mechanical arrangement—information to give in specifying control apparatus.

Function of Control

Proper understanding of an electric controller requires that it be considered as a part of the motor; the controller should be designed to take care of the functions not incorporated in the motor design, in order to enable the latter to operate under the specified conditions of load. Every motor has certain inherent characteristics which enable it to adapt itself to some of the conditions encountered in practice. In many cases, however, the motor would be very expensive and also very inefficient if it were given the necessary characteristics to prevent its being injured or to prevent injury to the load during the cycle of operation. The functions usually supplied by the controller are as follows:

To Limit the Current During the Acceleration of the Motor

The ohmic resistance of a motor is very low, so that when connected to the line while it is at rest a very large current would be drawn from the line if external resistance were not used to limit this current. As the motor accelerates it develops a counter e.m.f., which reduces the voltage available for causing a current to flow; hence the current is reduced. The current at any instant can be calculated by subtracting the counter e.m.f. from the line voltage, and dividing the result by the ohmic resistance in circuit. It is evident from the above that as the motor increases in speed the line current decreases and the starting resistance may be reduced, until the motor is finally connected to the line without any external resistance. The short-circuiting of this starting resistance can be done in several different ways.

Some direct-current motors are designed to be accelerated from rest, without the use of external starting resistance; these motors are, however, for use in particular applications. The squirrel-cage induction motor, in small sizes, can also be started by connecting it directly to the line.

To Limit the Torque During Acceleration

The torque of a motor is proportional to the current multiplied by the field strength. It is often desirable to start a motor with a gradually increasing torque; this can easily be done with a shunt motor by starting it with zero field strength. The shunt field of the motor is connected to the line at the same time as the armature. Since it takes an appreciable time for the field to build up to full strength, the torque will increase gradually and give an easy start. In this way a shunt motor can be started with twice full-load current, or even greater current, and not cause a shock, or jar, to the motor or apparatus to which the motor is connected. A series or compound motor, started in the same way, will build up its torque much faster. The induction motor also builds up its torque rapidly. No motor, however, will build up its strength instantly, so that it is not likely that any type of motor will give a hard shock to the machinery if it is started with zero field strength.

To Change the Direction of Rotation of the Motor

In many classes of service the motor is required to reverse its direction of rotation repeatedly. It is a well-known fact that the direct-current motor can be reversed in rotation, by reversing the current through the armature, and keeping the field in the same direction. The induction motor can be reversed by reversing one of the phases, and this is usually done by interchanging any two leads on a three-phase motor, or interchanging the two leads in one phase of a two-phase motor. Where the motor operates continuously in one direction, these connections can be adjusted at the time of installing the motor, but where the reversal of rotation occurs frequently, some substantial form of reversing switch should be included in the controller.

To Limit the Load of the Motor

This is usually done by means of fuses, or a circuit breaker. Where the main line switches are operated by magnets, an overload relay is used to de-energize the magnet and allow the switch to open. All overload devices should be provided with some form of time element attachment, usually a dashpot. This will allow the motor to take a short peak load of a few seconds duration without disconnecting itself from the line. This is very desirable, as such short-time peaks occur during acceleration, and often during the normal operation of the motor.

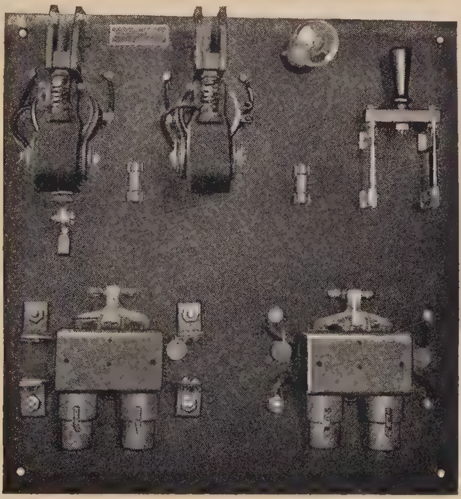


Fig. 1. Crane Protective Panel

The illustration shows a panel suitable for a crane equipped with three motors (overload relays at bottom). Where the number of motors is more or less, the number of relays are changed to correspond so there is one overload relay coil for each motor and one totalizing relay coil.

Sometimes an overload relay is provided for inserting the starting resistance in the motor circuit in case of overload. This arrangement is required in special cases where it is undesirable to have the motor torque entirely cease. Such relays are sometimes called "jamming relays."

To Disconnect the Motor upon Failure of Voltage

The voltage supply sometimes fails, and a serious injury might result upon the re-establishment of voltage if the motor were left connected to the line without the starting resistance. Manually-operated starters and controllers are provided with a latch, held in place by a shunt magnet. This latch retains the controller in the running position. Upon failure of line voltage, the catch is released and the controller is mechanically returned to the starting or off position.

Magnetic contactor control automatically returns to the off position upon failure of line voltage, as the magnets are de-energized under such conditions. The controller can be connected so that it will automatically start the motor again upon return of voltage to the line, in which case the device is known as "low voltage release." Where it is necessary for the operator to perform some function, such as pushing a button after failure of voltage, the device is known as "low voltage protection." The latter is the one usually required, as an operator may be working on the machinery, and there is danger of its being started automatically and injuring him upon return of voltage.

To Regulate the Speed of Rotation

Frequently a motor is connected to a load requiring different operating speeds. This speed change can be effected in several different ways, the common ways being:

Armature Control.—This consists in putting resistance in series with the motor. Direct-current motors have this resistance in the armature circuit, and the voltage across the motor brushes is less than the line voltage, due to the drop through this external resistance. Wound secondary induction motors are controlled in a similar way, by connecting the resistance in the secondary circuit. The drop in speed is in this case a little more complicated to calculate; the reduction in speed is proportional, however, to the voltage drop through resistance. Motors controlled in this way are called "variable speed motors." The speed at which the motor operates depends directly upon the torque required by the driven load. A change in torque causes a corresponding change in current, and the drop through the external resistance is equal to the current multiplied by the ohms.

Changing the Field Strength of direct-current shunt motors varies their speed. This is usually done by connecting a rheostat in series with the shunt field winding of the motor. Such motors are called "adjustable speed motors," since the speed remains practically constant under all conditions of loading. Commercial motors of this type are built with speed ranges as high as four to one. At present no alternating-current motors of this class are in commercial use.

Changing the Voltage of the Supply Circuit also varies the speed of a motor. This is usually done by supplying each motor from a separate generator. This system of control at present is applied principally to elevators, mine hoists, and reversing steel mill motors.

To Start and Stop the Motor at Fixed Points in the Cycle of Operation, or at the Limit of Travel of the Load

This feature can be obtained by the use of limit switches, which are operated by the machinery to which the motor is attached. They usually interrupt only a small circuit, thereby opening magnetic contactors which, in turn, disconnect the main motor circuit. These limit switches may be connected by gearing to the driven machinery, in which case they are called "geared" limit switches. Where the limit switches are mounted along the runway, and operated by the machinery striking the switch, they are called "track" or "hatchway" limit switches.

To Stop the Motor

The motor can be brought to rest by either friction or dynamic braking.

Friction Braking is accomplished by a mechanical brake, which is usually applied by a heavy spring and released by a magnet in series with the main circuit of the motor. In this case the brake is set whenever there is no current in the motor, and consequently no special arrangement is necessary on the controller to apply the brakes.

Dynamic Braking requires at least one additional switch on the controller. It is accomplished by disconnecting the armature from the line and short-circuiting it on itself through a resistance with full field strength, the energy stored in the rotating parts being dissipated in heating the resistance.

To Protect the Operator from Injury

It is very important to ensure the operator who uses the machinery against injury either during the starting of the motor or during the subsequent operation of the machinery. This requires the control apparatus to be properly protected, so that there is little danger of the operator's receiving a shock, or being burnt by an arc, in starting or during the operation of the machinery. Accidents may occur which require quick stopping of the machinery. To effect this result, safety stop devices are frequently placed around the machinery, which are either operated automatically or manually, depending upon conditions. These devices must be adapted to each particular application, but are very important, and should be carefully considered by engineers in specifying the electric drive.

Classification of Control Apparatus

Electric controllers can be roughly divided into two general classes: (1) Manual Acceleration, (2) Automatic Acceleration.

1. Manual Acceleration

This class comprises control apparatus in which the acceleration of the motor is entirely under the control of the operator. Illustrations of this are the face plate and drum type controllers.

2. Automatic Acceleration

This class comprises control apparatus in which the acceleration of the motor is performed automatically.

These terms are usually applied to the method of acceleration. Controllers may have a combination of these two methods; for example, a magnetic contactor type of crane controller may have a master switch with five or six notches. The acceleration between notches is automatic, but the operator can determine the direction of rotation and the speed of the motor. The rate of change in speed, however, is automatic.

Controllers, including starters, may be divided into the several groups given below. These groups do not include every type built, but give a good idea of present practice. The advantages and limitations listed must be interpreted in a very general manner as they may not apply in many special cases. The magnetic contactor controller is usually automatic. The other types are generally manual; but automatic acceleration may be obtained by using an electric motor or an air cylinder to operate them.

1. Face Plate Controllers

Advantages:

1. Low price.
2. Compact, usually with self-contained resistor.
3. Easy to mount on wall or switchboard.
4. Flexible design, can be readily altered.
5. Renewals of contacts and repairs inexpensive.
6. Low voltage protection feature easily applied.

Limitations:

1. Design not usually well adapted to take care of arcing. For this reason it is not good for heavy or frequent service.
2. Design usually not rugged mechanically.
3. This type presents difficulties where the connections are complicated, such as a reversing control for wound secondary motors.

2. Lever Control (this Type Consists of Individual Contactors, Each Operated by Its Own Lever or Handle)

Advantages:

1. Medium price.
2. Panel-mounted—may have self-contained resistor.
3. Can be readily combined with a circuit breaker.
4. Flexible design—can readily make up special combination.
5. Can use rolling contact.
6. Closing and opening of contact positive.
7. Low voltage protection feature easily applied.

Limitations:

1. Requires the manipulation of a number of handles.
2. Not suitable for quick operation.
3. Can not be readily enclosed to protect operator.
4. Not as compact as the drum type.

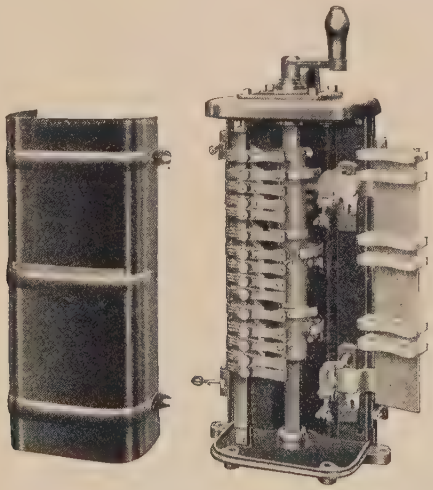


Fig. 2. A modern type of drum controller, cover removed

3. Drum Controller (Cylinder Type)

Advantages:

1. Low price in small and medium sizes.
2. Compact, but separately mounted resistor.
3. Entirely enclosed. Can be made dust-proof, spray-proof, or gas-proof.
4. Strong mechanically and simple to operate.
5. Can have various mechanical retarding devices attached to prevent too rapid acceleration.
6. Complicated connections can be made; *i.e.,* forward and reverse, or power and brake, on the same drum.

Limitations:

1. Difficult and expensive to modify design.
2. Frequent inspection and adjustment of contacts necessary.
3. Rapid deterioration of contacts under severe conditions.
4. Sometimes difficult to take care of the energy of the arc.
5. Limitation as to size.
6. Large sizes difficult to operate.

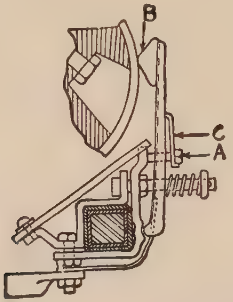


FIG. 3. Drum controller, sectional view, showing sliding contact made between finger B and segment

4. CAM CONTROLLERS DRUM-MOUNTED (MANUALLY OPERATED)

Advantages:

1. Low price.
2. Compact design but resistor separately mounted.
3. Entirely enclosed and can be made dust-proof, spray-proof or gas-proof.
4. Strong mechanically and simple to operate. Can be provided with reciprocating as well as rotating handle.
5. Can have various mechanical retarding devices attached to the handle to prevent too rapid acceleration.
6. Complicated connections can be made readily.
7. New combinations can be made easily by changing the number of units and the shape of individual cams.
8. Rolling contacts are used which are usually free from welding.
9. Contacts are easily and cheaply renewed.
10. Entire unit can be replaced if necessary.
11. Easy to inspect.
12. Quick closing and opening not found in drum controllers.
13. Combines simplicity of the manual controller with the durability of magnetic control.

Limitations:

1. The larger sizes require more power to operate than does a master switch.
2. On account of the enclosure the continuous capacity may be reduced and the energy of the arc must be limited.
3. Limitations in size.

5. CAM CONTROLLERS PANEL-MOUNTED (MOTOR OPERATED)

Advantages:

1. Compact design.
2. The necessary complicated sequences of operation easily obtained.
3. Positive time element obtained through pilot motor and gearing.
4. The motor may be replaced by an air cylinder when air pressure is available.
5. A rolling contact is obtained which is free from welding and gives long life.
6. Contacts are easily and cheaply renewed.
7. Entire unit can be replaced if necessary.
8. Easy to inspect.
9. A saving in copper connections, as the controller can be located close to the motor, and the master switch wherever convenient.

Limitations:

1. Expensive in small sizes.
2. The cycle of operation must be completed in order to restore the controller to its normal position. This may require too long a time element for fast service.
3. The number of contactors which are usually mounted in a row is limited by the size of the panel.

6. MAGNETIC CONTACTOR CONTROL

Advantages:

1. Long life of contacts due to the rolling action and a quick opening and closing.
2. Positive opening and closing of contacts.
3. Flexibility in adapting controller to various designs.
4. Can be arranged with various safety attachments.
5. More "fool-proof" than other types.
6. Strong and rugged mechanically.
7. Automatic control can be obtained.
8. Contacts are easily and cheaply renewed.
9. Entire unit can be replaced if necessary.
10. Easy to inspect.
11. A saving in copper connections, as the controller can be located close to the motor, and the master switch wherever convenient.
12. A time element in closing and opening not found in drum controllers.

Limitations:

1. More expensive than manual controllers.
2. The larger sizes occupy considerable space.
3. The wiring diagram is complicated.

7. Liquid Controllers

Advantages:

1. Large thermal capacity for starting.
2. Very gradual change of resistance.
3. Absence of arcing or other wear, as no contacts are used (except line switch).
4. The resistance can be easily adjusted by varying the amount of soda in the solution.
5. It can be readily adapted for automatic operation.

Limitations:

1. Considerable floor space is required.
2. The electrodes are subject to corrosion.
3. Cooling water is required for the larger sizes.
4. The use of the liquid limits its application.

In specifying control apparatus, the following information should always be given:

1. The characteristics of the power circuit, such as voltage, frequency, number of phases, voltage regulation.
2. A brief description of the control apparatus required.
3. If the motor speed is to be adjusted, the speed range should be given, the load at the maximum and minimum speed and the number of speed points.
4. The cycle of operation should be stated in detail, particularly the number of starts made by the motor per hour.
5. A description should be given of the machine which the motor drives, particularly the torque required to accelerate to full speed.
6. A description of any unusual features of the installation, such as moisture, dust, acid fumes, limited source of power, space available for the apparatus, etc., should be noted.
7. Complete rating (nameplate reading of the motor).

All of this information is necessary for the intelligent selection of both the motor and control. In the absence of any of this information, the engineer furnishing the electrical apparatus must guess at the requirements on the basis of the best average practice. This will often take care of the situation, but exact information is very much better.

SUMMARY OF CHAPTER I

The function of control is to supply what the motor lacks: thus, the controller may

limit the line current during the motor's acceleration;
limit the torque during the motor's acceleration;

- reverse the motor's rotation;
- limit the load on the motor;
- disconnect the motor when voltage fails;
- regulate the motor's speed;
- automatically stop, or stop and start, the motor;
- brake the motor.

Very small motors can be connected directly to the line without starting resistance.

By connecting the motor armature and the field to the line at the same time, the torque, owing to the time required for the field to build up, increases gradually and hard shock to the machinery is avoided.

The rotation of direct current motors may be reversed by reversing the current through the armature; of alternating current motors, by reversing a phase.

A jamming relay is one that re-inserts the starting resistance in the circuit in case of an overload.

With low voltage release, the motor after stopping starts again on return of voltage to the line. With low voltage protection, the motor after stopping does not start on return of voltage to the line.

The speed of a motor may be regulated,

- by inserting resistance in series with the armature;
- by inserting resistance in the secondary (wound rotor) circuit (variable speed motors);
- by varying the field strength (adjustable speed motors);
- by varying the supply voltage.

Limit switches enable the motor to be stopped, reversed, etc., by the driven machinery; "geared, limit switch" (geared to the machine); "hatchway limit switch" (mounted on runway and struck during the travel of the machine).

To obtain dynamic braking, full field is maintained and the armature, after being disconnected from the line, is short circuited on itself. Sometimes after the motor slows down a friction brake makes the final stop.

For the protection of the operator, safety or emergency stop devices should be located on the machinery where needed.

Motors may be accelerated by controllers manually operated (manual acceleration type) or operating automatically (automatic acceleration type).

Examples of various types of controllers are:

- face plate type;
- lever type;
- drum type;
- cam type, drum mounted (operated manually);
- cam type, panel mounted (motor operated);
- magnetic contactor type;
- liquid type.

CHAPTER II

HISTORICAL

Earlier forms manual—certain developments due to requirements of special applications—electric railways (drum controller)—elevators (systems of speed control, methods of acceleration)—machine tools (adjustable speed and reversing planer motors)—steel mills (rugged designs—magnetic versus manual types—simplifying the system of control—current limit acceleration, two methods—future developments.

In order to obtain a proper perspective of controller practice, it is necessary to know something of the events which lead up to the present state of the art. This chapter will not give a complete history of industrial development and it must, to a considerable extent, be limited to the personal experience of the author. A sufficient number of important stages in the development will be outlined to enable the reader to understand how present practice has been developed.

The earlier forms of control were manually operated. They were usually for d-c. motors and consisted of a line switch and a resistor for limiting the starting current, together with means for short-circuiting this resistor. Sometimes the line switch contained means for reversing the motor. The most common form of starting device became familiarly known as a "starting rheostat." The other devices were known as "reversing controllers," whether they controlled the speed of the motor or merely started it. The automatic controller followed the manual controller and in many cases was quite complicated, most of the controllers involving the use of a dash-pot, which was combined with weights or magnets to control the cutting out of the resistor during acceleration.

Most of the early controller development took place in the railway and elevator fields. The former was carried on in connection with the series motor, the latter with the shunt motor, which was usually compounded during the starting period. A study of the early patent art shows a marked difference in the development of these two lines of control apparatus. This distinction exists today to a considerable extent; railway control concerning itself chiefly with the series motor; elevator control has broadened into industrial control and deals with shunt, series and compound motors for a variety of applications.

T.M.E.R.&L.CO. MILWAUKEE

1. CONTROL FOR SERIES MOTORS, PRINCIPALLY IN THE ELECTRIC RAILWAY FIELD

Upon use of motors in connection with trolley cars it was found convenient to locate the controller on the platform of the car. This led to the compact enclosed type of controller, its principal representative today being the drum type shown in Fig. 247, Chapter XXVI. This usually consisted of a cylinder, rotated by a handle, with contact segments which engaged stationary flexible fingers. Some of the earlier designs consisted of a rotating cam shaft actuating individual contactors. There were also various modifications of these two arrangements. The cylinder type of control proved the cheaper and better commercially. The weak point of this controller is in the contact fingers which require frequent adjustment and are apt to stub or bend when the drum contact meets the finger in the direction of the finger support. Many types of fingers were devised to minimize this difficulty; and quite a variety of designs are in use today.

At first, the cylinder holding the contacts was made of wood (see Fig. 16), and the fingers themselves supported on wooden bases. The contacts and finger supports were attached to the wood by means of ordinary wood screws. If moisture was present in the wood, a small leakage current would be set up between the screws, which charred the wood around the screw and ultimately loosened the contact or finger support.

The most important improvements were the use of the "magnetic blow-out" for extinguishing the arc and the substitution of a metal cylinder for the wooden cylinder, the contact strips being attached with machine screws. The metal segments of the cylinder are clamped to a square or hexagonal shaft insulated by tubing made of various materials. The finger supports which were first attached by wood screws were afterwards clamped to the wooden bases by through bolts. Later the wooden bases were discarded and insulated steel bars substituted, the finger supports being clamped to these bars.

Another early form of controller consisted of the commutator type placed under the front platform and operated by a system of rods and levers.

The earliest system of control was an ordinary rheostatic reversing controller, the motor being connected to the line through resistance, which was afterwards short-circuited. The construction of a trolley car required the use of two and sometimes four motors. Advantage was taken of this plurality of motors to place the two motors in series to obtain a slow-operating speed and to give the necessary starting torque with a minimum line current. After the motors had been accelerated to half speed, they were changed to full speed by connecting them in parallel with resistors in series and afterwards short-circuiting the resistors.

The latter system of control presented a new problem, that of changing from the series to the parallel connections. The three methods of accomplishing this are explained in the chapter on Series Parallel Control.

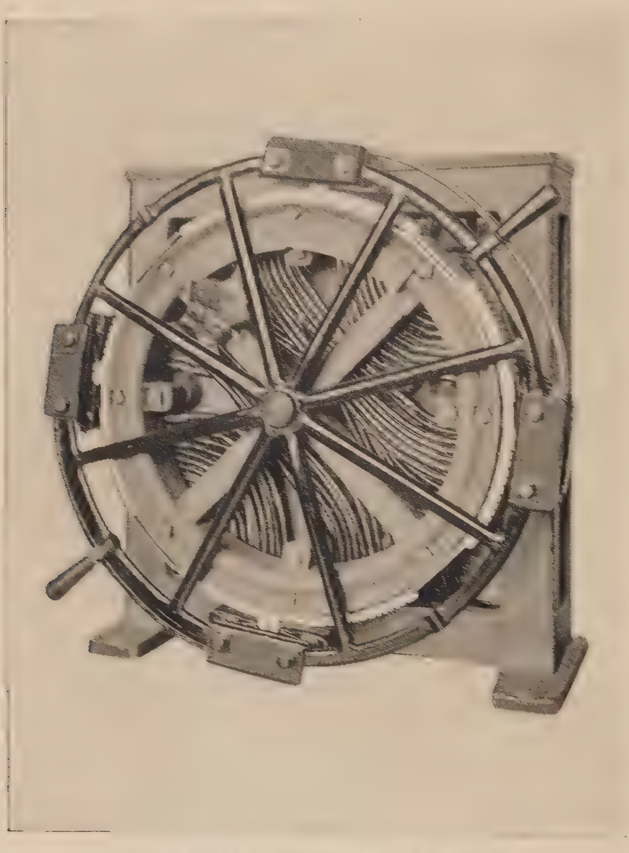


Fig. 4. D-c. Commutator Controller

This is an early type of reversing controller built prior to 1900. It was used for crane and hoist applications. The fundamental idea is that of a controller with a set of commutating segments similar to the commutator on a d-c. generator

When it became desirable to connect several cars together to form a train, some form of central control was necessary. One of the early types provided for operating the control for each car by means of an electric motor, known as a pilot motor. A later modification in this system substituted air cylinders with magnet valves for the pilot motors.

In later railway development, contactors are used in groups, together with remote control reversers. These contactors and reversers are operated either by electro magnets, or by air cylinders with magnet valves. The general use of compressed air for other parts of railway equipment makes its extended application for actuating the control equipment both convenient and economical. Some air-operated industrial controllers have been installed, but their application is limited, since compressed air is not usually available.

2. Control of Shunt and Compound Wound Motors

Most of the early development of shunt and compound wound motor control was in connection with elevators. At first a manual controller was used, mounted close to the motor and actuated from the elevator car by means of a rope or some form of lever device. This followed closely the hydraulic practice for actuating valves and needed no new development as far as the actuating means was concerned. Many slow speed elevators today use a hand rope control, but the hand rope operates only the reverse switch, the acceleration being performed by separate means, usually magnetic contactors.

When the operating rope or lever was moved, it first closed the direction switch (which was often separate from the line switch) and afterwards the line switch, which in turn actuated automatic accelerating means. This consisted of a weight operating against a dash-pot and retarded by a coil in series with the armature. The weight moved an arm across a set of contacts which gradually short-circuited the starting resistance and afterwards the series coils, causing the motor to operate as a shunt motor. These controllers gave only one elevator car speed and were satisfactory for slow-moving cars. Another form of accelerating means was a magnet connected across the armature of the motor for lifting an arm which short-circuited the starting resistance. In another arrangement the magnet was connected across the starting resistor, using the drop across this resistor to retard the cutting out of the resistance during acceleration. Many combinations of these devices were used, but electrical and mechanical difficulties resulted finally in the adoption of magnetic contactor control. It might be interesting to note that pilot motor control was used quite successfully on a number of elevator installations about 1898. This pilot motor actuated a face plate controller, which not only short-circuited the starting resistance, but changed the motor speed by changing its field strength and also provided for dynamic braking. One of the limitations of this control, apart from its expense, was the length of time required for the pilot motor to return the arm to the starting position.

The contactor type of control developed later consists of individual magnetic contactors. Sometimes these are two-pole for use as combination direction and line switches. The contactors used for short-circuiting the starting resistor are actuated in several ways:

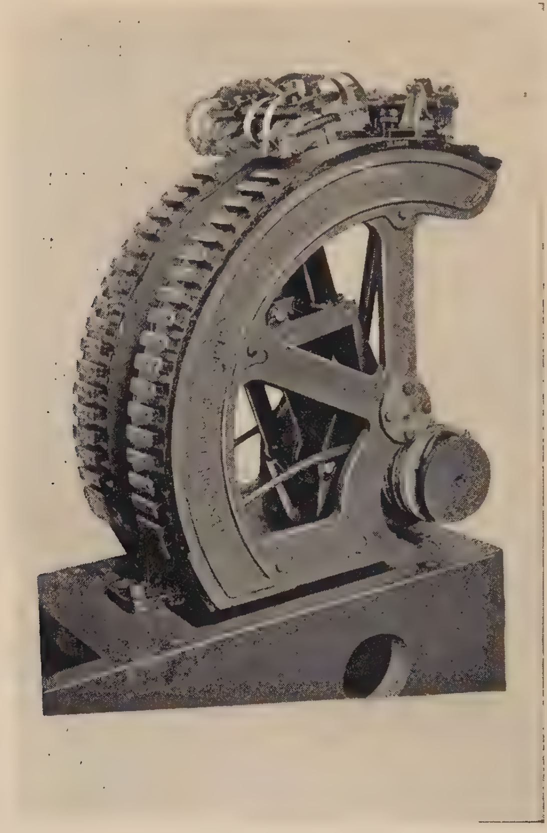


FIG. 5. A-c. Commutator Controller

This controller was made for use with a polyphase a-c. motor in which a segment of a circle was used instead of the complete circle as shown in Fig. 4

1. The shunt coils are connected across the armature of the motor and the contactors close in succession as the counter e.m.f. of the motor increases. This is known as counter e.m.f. method of acceleration.

2. The closure of the accelerating contactors is controlled by the main motor current and is known as current limit acceleration. This method

usually employs a relay or relays for governing the closure of the accelerating contactors. The details of this system will be given later.

3. The accelerating contactors may close at definite intervals of time without reference to the counter e.m.f. developed or the subsidence of the starting current peaks, by the use of "time element" relays.

About 1893, a prominent engineer experimented with elevator motors, controlling their speed by changing the field strength of the motor. These experiments were among the first in which the speed of a shunt motor was varied by changing the resistance in the field circuit. Very little was done with this method of control until recently. Its commercial development first took place in connection with machine tool drive and it was later used with high-speed elevators.

Another modification in the control system for elevators for obtaining a slow speed was the use of a resistance in shunt with the armature, as well as in series with the armature. The combination of shunt and series resistance, together with an adjustable speed motor, will give three operating speeds, a slow speed for making the landings, a speed representing the full field strength in the motor, and a third speed representing the weakened field of the motor. Usually these are sufficient, but additional speeds may be obtained.

Machine Tool Controllers

There are two other applications of electric drive; namely, the machine tool and the steel mill applications, which have exerted a very marked influence on controller development. The machine tool application has been principally responsible for the development of the adjustable speed d-c. motor and the controllers which are used with it. The study of machine tool requirements has produced several special motor and control combinations, the best known of which is the reversing planer equipment.

Steel Mill Controllers

The steel mill applications can be briefly divided into main drive and floor auxiliaries. The main drive uses motors of several thousand horsepower, the first of which was installed in this country in 1906. The motor is connected to a motor generator set and controlled by changing the strength of the field of the generator. This method will be described in a separate chapter.

The floor auxiliary devices in steel mills use series and compound motors that must be of very rugged design. The motors are made especially for this class of service and are known as the steel mill type. The controllers are also very heavy and rugged and must be liberally rated. Steel mill control problems differ from those of elevators and machine tools in dealing mostly with series motors. It was in steel mills that the lockout contactor found one of its principal applications.

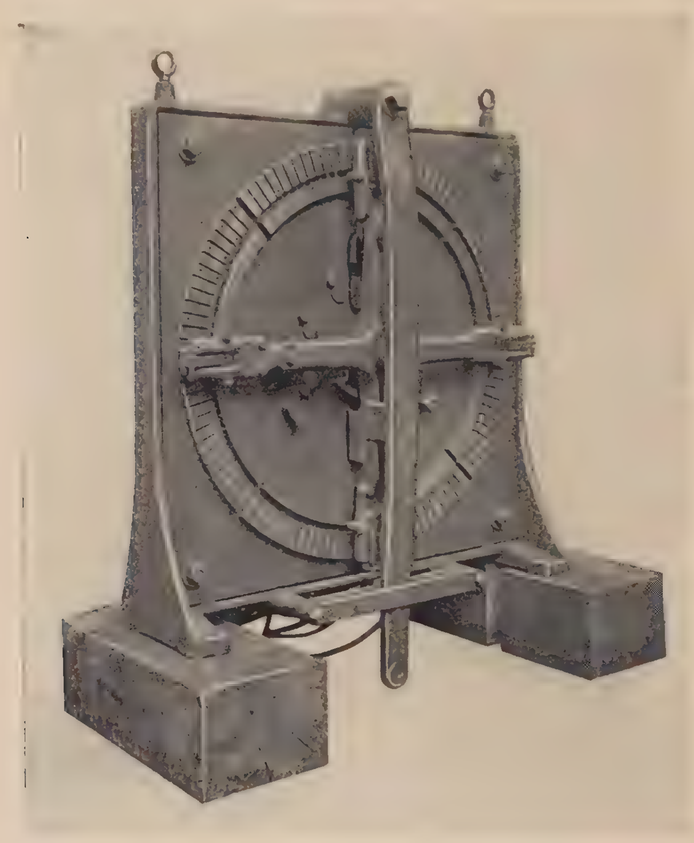


FIG. 6. A-c. Face Plate Controller

This is a development from the commutator type of control. In which the segments are mounted on the surface of the insulating plate, rather than around the periphery of the insulating material

The application of electrical apparatus to cranes, printing presses, and a number of other industries, has had its effect on controller development. It is for the purpose of bringing out the effect of these industries on controller types and systems that the applications are given in the latter part of this book.

Manual Controllers

The drum type controller has been briefly described. It is in extensive use today and is a very reliable device when applied within its capacity. Recently, the cam contactor type of control has been further developed.

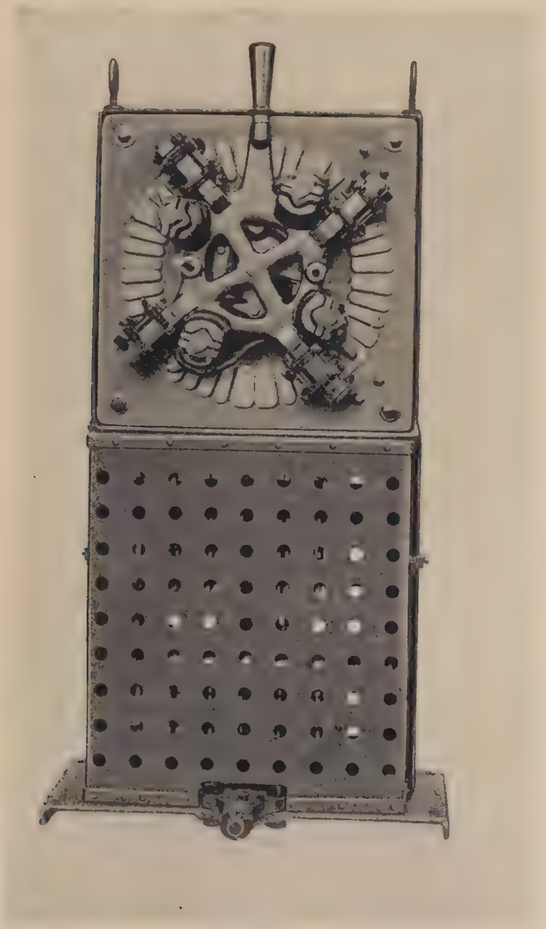


Fig. 7. D-c. Face Plate Controller of a More Modern Type

Fig. 190 shows a contactor type of controller, using the drum mounting. This development has been too recent to make definite statements of its range of application, but it is believed that it will extend the use of manually operated controllers and provide the desired flexibility to enable special controllers to be built readily and for a reasonable cost.

The commutator or grindstone controller, illustrated in Figs. 8 and 9, is not being built at present, as the cylinder and cam type of drum controllers perform the same functions for most applications and are more compact. It illustrates a type of design representing a great many controllers which have been in commercial use. There is a possibility that it may be used again, as the art advances.

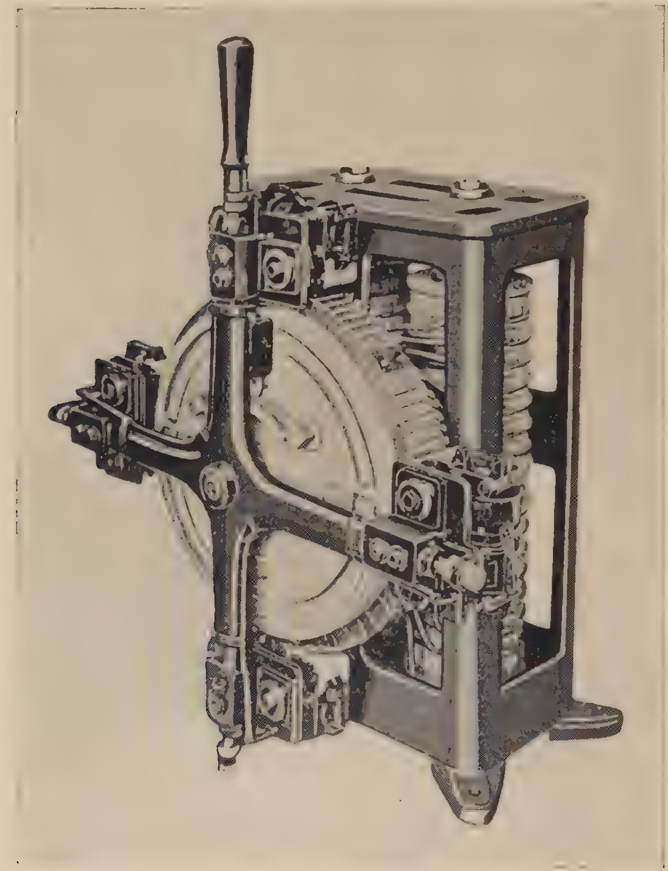


FIG. 8. A Commutator Controller Showing Modifications from Fig. 4

The face plate controller, illustrated in Figs. 6 and 7, is quite similar to the commutator type, except that the contact segments are placed on a flat surface, rather than around the arc of a cylinder. Some of these controllers are still being manufactured commercially. A great many of them were used in the past and proved very satisfactory. Their size and exposure are now somewhat against them, particularly since the safety requirements make it necessary to enclose them for many applications.

Under this heading should be included field rheostats, which may be either hand operated or motor driven, depending upon their size and application.

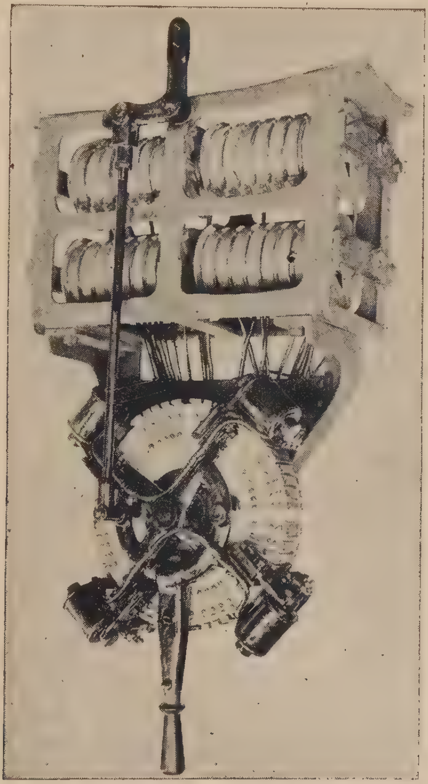


FIG. 9. Commutator or Grindstone Controller

A more recent development of the commutator type control. This shows an earlier form of resistor in which the units were wound up in a spiral with mica insulation and formed individual cells. This type has been superseded by the cast-iron grid

MAGNETIC CONTACTORS

This type of control is the preferable one at the present time for many applications. It is practically the only type used for automatic acceleration. A description of the detailed development of the magnetic contactor is very interesting and brings out many ingenious features. We shall have space only to mention a few of the more important changes.

Practically all the early contactors were actuated by magnets of the coil and plunger type. Theoretically, this is the most economical form of magnet, but its adaptation to practice developed a fundamental difficulty. The plunger passes through the magnetic frame, the magnetic circuit being completed between the upper end of the plunger and the stationary core. Where the plunger passes through the frame, it is necessary to provide a permanent air gap, usually consisting of a brass bushing. Although this introduces an appreciable air gap in the magnetic circuit when the plunger is brought in contact with the core, it is often necessary to use an additional brass washer to prevent the residual magnetism from holding the plunger against the core. These air gaps reduce the efficiency of the magnet. If the air gap, where the plunger passes through the core, was made small, it was impossible to keep the plunger from being pulled strongly to one side, which caused wear on the brass bushing and the further the bushing wore down, the greater was the side pull, due to unequal magnetic distribution. This not only introduced considerable friction in the movement of the plunger, but it caused rapid wear which increased the maintenance charge. In dirty places, dust and grit accumulate inside the coil and sometimes cause sticking of the plunger.

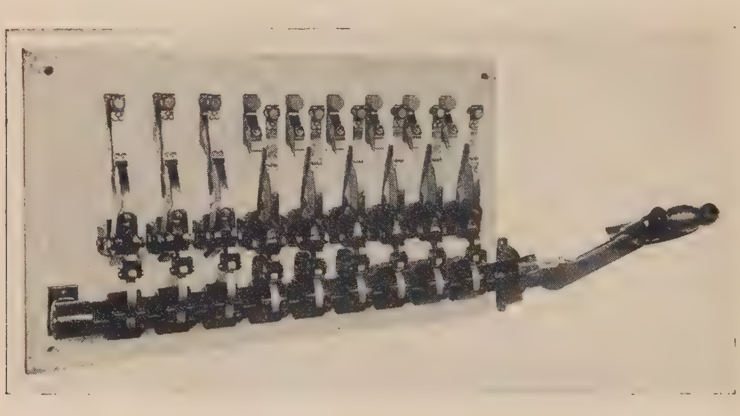


Fig. 10. Cam Contactor Control Built Prior to 1900

This form of control was the forerunner of the lever type controllers now in use. It consists of a series of contactors closed by cams actuated by a common handle

In the last few years, designing engineers have changed from the coil and plunger type to the clapper type of magnet. This has avoided the former difficulties and is proving very durable and satisfactory in practice.

The earlier forms of contactors employed a variety of contacts and these contacts were located sometimes at the top and sometimes at the bottom. In general, the design has settled down, so that the rolling type of contact is usually employed and the contacts themselves are located at the top of the contactor above the operating coil. The arc shields are arranged so that they can be revolved around their core in order to expose the contacts for inspection and repair. All contacts, operating coils, arc shields and other parts of the switch which may be injured, can be removed and replaced from the front of the board by one individual, unless the part is too heavy to be handled.

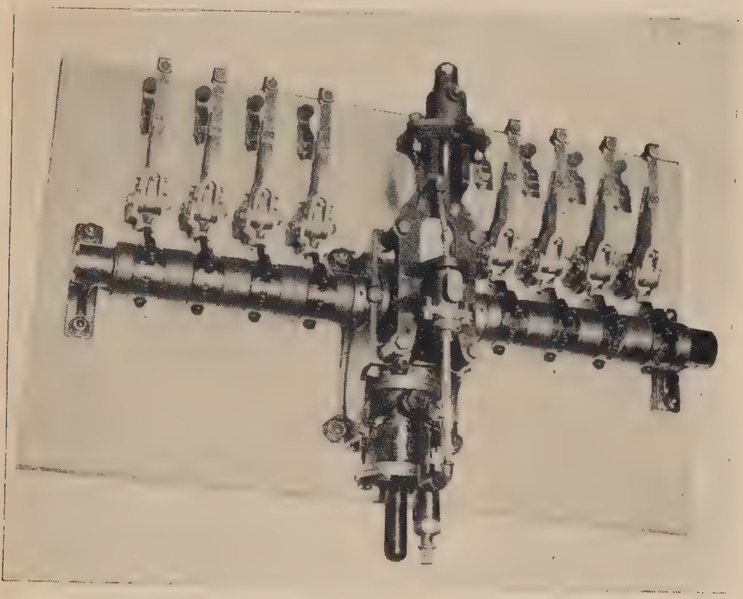


FIG. 11. Automatic Cam Controller

This illustrates an automatic controller of the cam type for use in connection with a pump. A pressure regulator controls a hydraulic cylinder which actuates the cam shaft starting the motor when the pressure decreases to a predetermined value. When the pump has increased the pressure to the proper amount, the pilot valve makes the necessary connections for returning the controller to the off position

Trouble with the earlier designs of contactors led to the practice of mounting each contactor on an individual base. If trouble developed which could not be readily repaired by the electrician, the complete contactor, including its base, was removed and a new contactor with base mounted in its place. This practice is being followed at present by some manufacturers. It results in a larger and more expensive structure than necessary and does not present as good an appearance. The modern contactor is so well designed that very little trouble is experienced with the magnet frame. All of the parts which might be affected can be readily removed from the front of the board, so that there is no further necessity of using individual bases for each contactor; in fact, it is easier to dismantle the contactor from the front of the board than it is

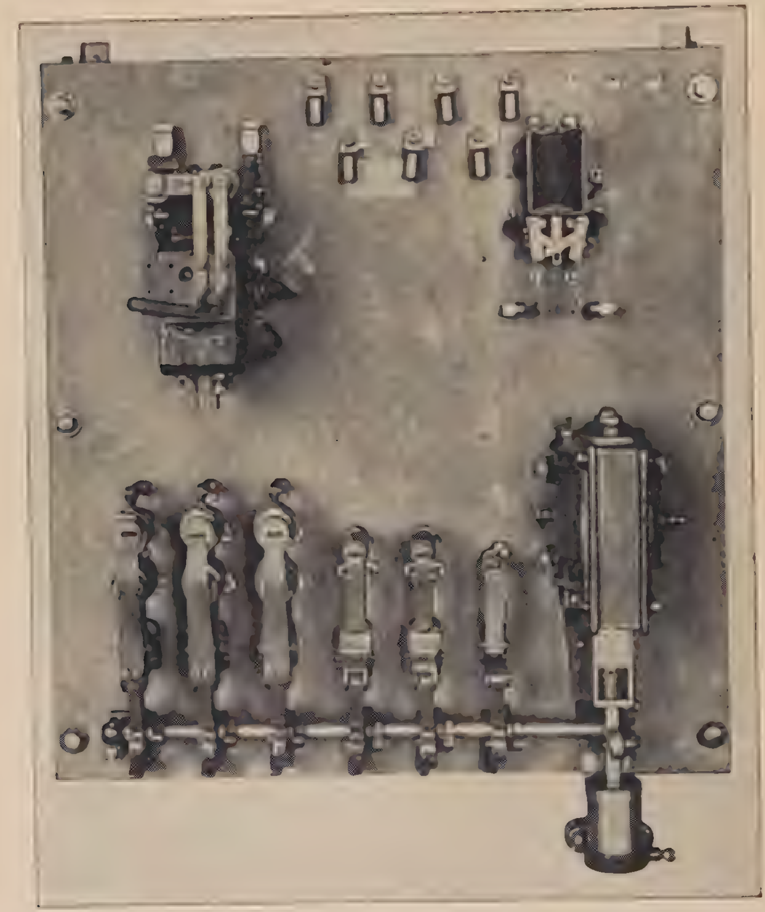


FIG. 12. A-c. Automatic Cam Controller

This shows a series of cam contactors actuated by an a-c. magnet, the time element being determined by a dash-pot

to disconnect all of the wiring and substitute a new contactor and base complete. This change in construction has a very important bearing in places where it is necessary to provide cabinets or guards around the control apparatus, as the space requirements become an important item and a compact control panel is desirable.

SIMPLIFYING THE SYSTEM OF CONTROL

When automatic control was first introduced, it was found to be comparatively easy to provide a great many different safety connections. For instance, the line contactors were interlocked electrically with the accelerating contactors, so that all of the latter must be opened before the line contactors were closed. With the old coil and plunger type of magnet, the sticking of a contactor might occur quite frequently and such an arrangement was necessary. With the modern design of clapper contactor, these interlock connections have been abandoned. The older design of controllers was characterized by many electrical interlocks and much complication of the detail wiring. The recent tendency has been very

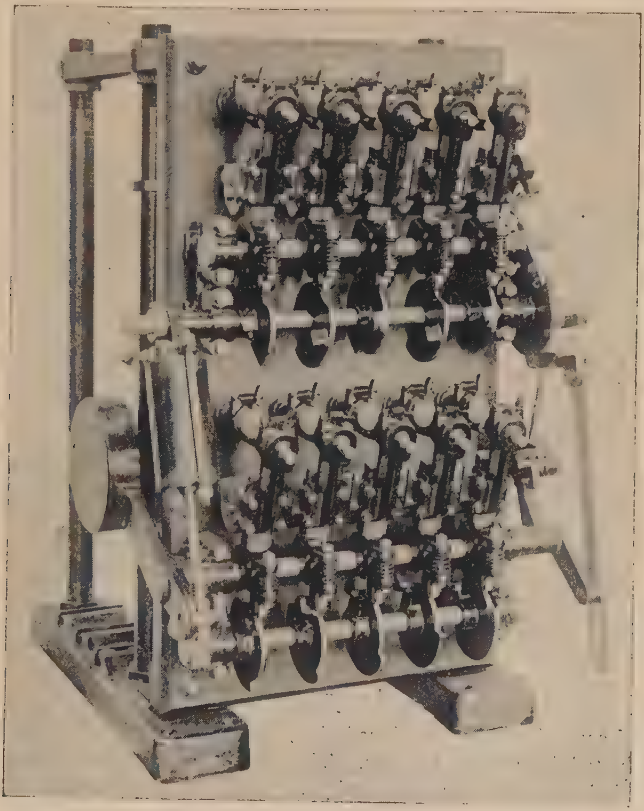


FIG. 13. Automatic Cam Type Elevator Controller

This illustrates a series of cam contactors actuated by a weight and controlled by a dash-pot. This controller was introduced prior to 1907 strongly towards a simplification of the control wiring. Electrical interlocks are apt to give trouble and should be avoided wherever possible. By comparing the modern diagram for a reversing control with one in use ten or fifteen years ago, a marked improvement in this respect will be noted. An interlock connection should not be used unless the damage from its omission will be greater than the trouble which might be experienced from its failure to operate. One of the points of merit in a control panel is the small number of electrical interlocks. With these improvements, the magnetic contactor control has become an exceedingly reliable piece of apparatus and comparatively easy to understand.

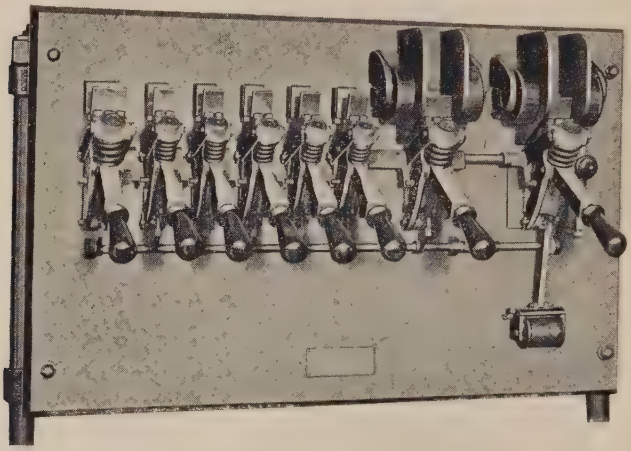


FIG. 14. Lever-type Controller

This form of controller was introduced about 1904 and consists of a series of lever switches actuated by starter handles. This controller shows the rolling contact which has since been universally adopted for magnet contactors

Automatic controllers have inherently many advantages over manually operated controllers. Primarily, the contactor is an ideal device for opening and closing a circuit, for the reason that its operation is positive and not under the control of the operator as to the rapidity with which circuit is established or interrupted. Moreover, automatic control systems may be designed to accomplish many results impossible of achievement with manual control systems, and finally, it should be noted that as contactor type controllers are handled by means of light moving master switches, the element of personal fatigue which enters into the operation of manual controllers of large capacity is entirely eliminated, enabling operators to attain a higher daily mark of production.

Current Limit Acceleration

Very little change has taken place in the counter e.m.f. method of acceleration or in the dash-pot method, except that dash-pots have been materially improved recently. The principal developments in accelerating systems have had to do with the current limit method. This can be broadly divided into the relay type and the lockout contactor type.

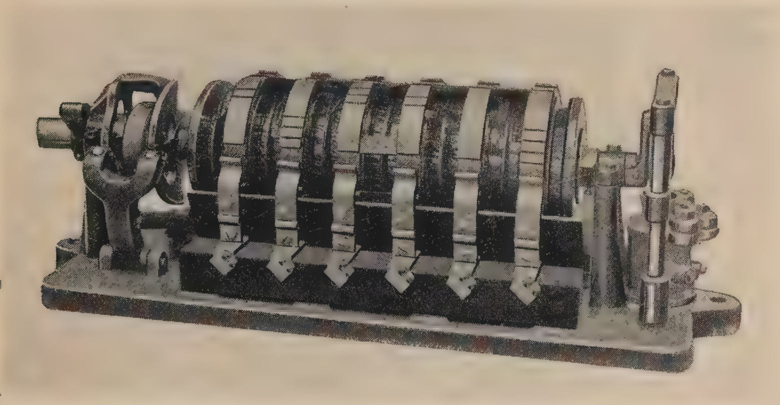


Fig. 15. Automatic Elevator Controller

This controller is of the drum type having the resistor units forming part of the drum. Note the use of wood as insulating material. This form of controller was used about 1902

The relay type was used much earlier than the lockout contactor type (the latter coming into use about 1912). Originally only one relay was used for each controller, being transferred to each contactor circuit in turn. The contactors had two coils, one of which was known as the closing coil, controlled by the relay, the other a holding coil, which was sufficient to retain the switch in the closed position. The relay alternately opened and closed at each current peak, thus retarding the acceleration. It was afterwards found that a single coil on the contactor was sufficient if a four-point interlock were used. This interlock transferred the contactor circuits to the relay in succession. This arrangement was economical in the use of relays, but the extra interlocks were expensive and frequently became sources of trouble. At this time, a limited use was made of a single relay having a series of connections, one to each contactor. It was found very difficult to maintain all of these connections through the relay, but the advantage of eliminating the interlock was sufficient to warrant the use of an individual relay for each contactor. This reduced the auxiliary contacts to the present practice which is followed to some extent without extra precautions. This arrangement causes the relay to open and close its contacts each time the motor is accelerated and a further improvement consisted in mechanically holding the relay open by the preceding contactor, so that the function of the relay was only to make contact. Even this improvement was not ideal,

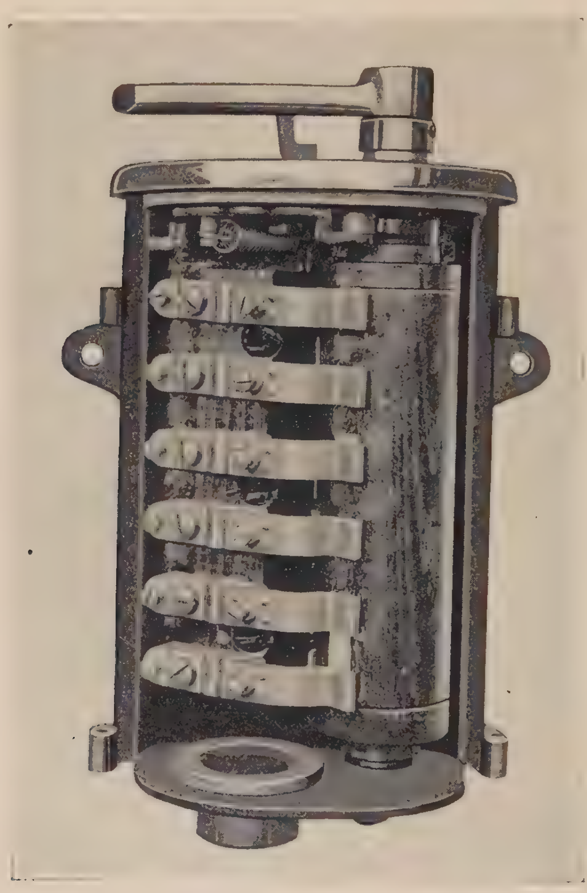


FIG. 16. Drum Controller Showing the Use of a Wooden Drum and Wooden Finger Base Support

A construction in common use about 1902, now superseded by a more substantial design

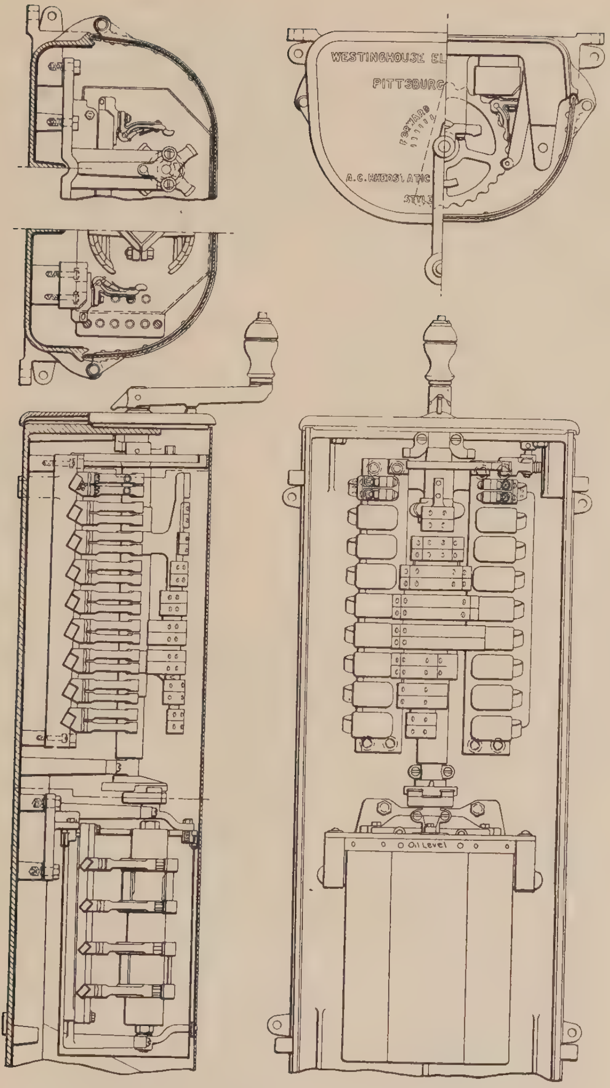


FIG. 17. Drum Controller for 2200-volt a-c. Motor

This shows a modern construction of drum made up of metal segments clamped to an insulated steel shaft. The contacts for the primary of the motor, which is connected to a 2200-volt supply line, are mounted in an oil tank at the bottom of the controller

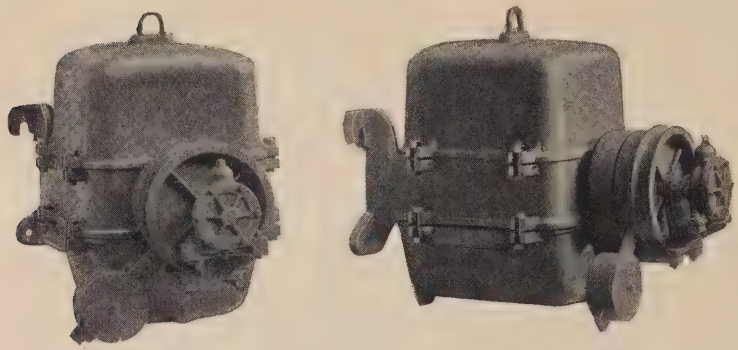


Fig. 18. Automatic A-c. Pump-controller Autotransformer Type

This illustrates one of the earlier forms of pump controllers for a-c. motors. It consists of a standard starter having an automatic device attached in place of the handle. The sheave wheel is connected by ropes to a float in the tank to which the pump delivers water. The raising and lowering of the water level throws the weight over center and actuates the controller to either start or stop the motor. The time element is controlled by a dash-pot

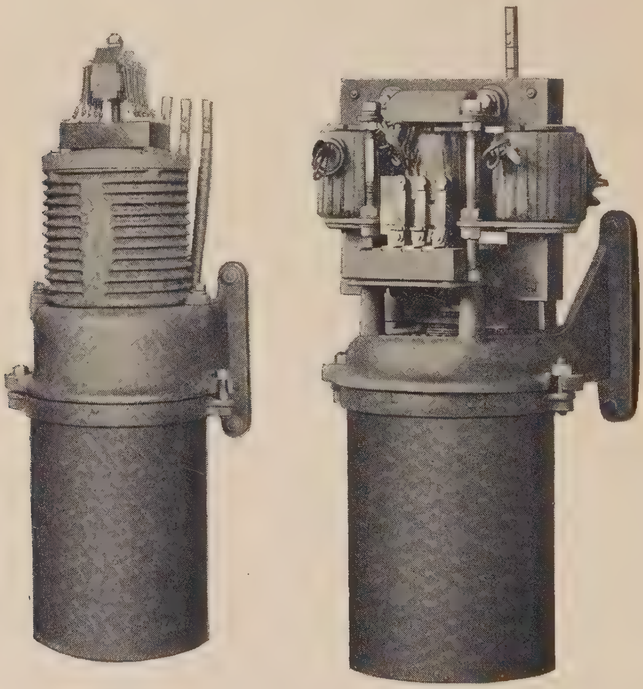


Fig. 19. A-c. Oil Immersed Contactor

This shows two early forms of oil-immersed contactors actuated respectively by a d-c. or an a-c. magnet. These forms of contactors were also actuated by air cylinders. The contacts are on the lower part of the structure and are immersed in the oil tank as the magnetism in the relay takes an appreciable time to build up after the current has decreased to the low value. Sometimes this would permit the relay to drop and touch its contacts before the magnetism had reached its maximum value. To overcome this, some engineers wound the relay with compound coils, which over-magnetized the relay until it was time for it to operate. For large motors, the extra copper connections added a great deal of expense. Arranging the mechanical interlock of the

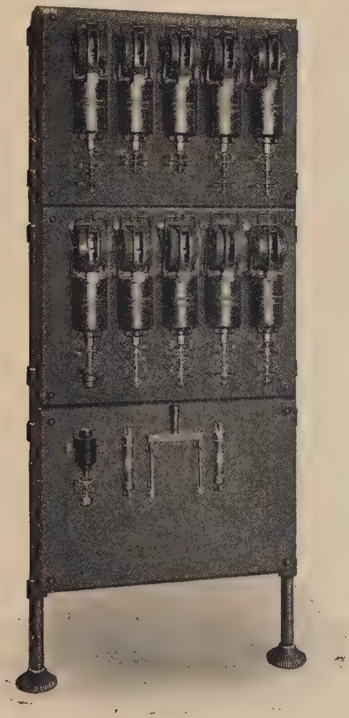


FIG. 20

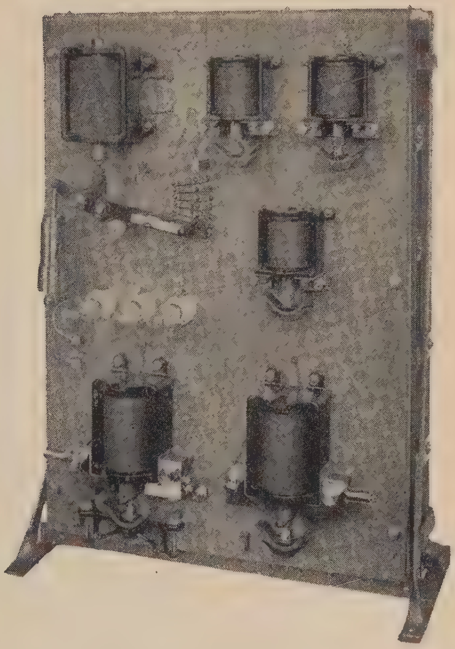


FIG. 21

FIG. 20. D-c. Elevator Control Magnetic Contactor Type

This shows an earlier form of magnetic contactor. The acceleration is controlled by a series relay. The first contactor is provided with a dashpot to give a fixed time element in order to take care of the initial rush of current on the elevator. Note the complicated set of interlocks. The progress in the art has resulted in eliminating most of these interlocks

FIG. 21. Automatic Starter for D-c. Motors

Using a dashpot for a timing device. The dashpot switch is a master controller supplying power to the operating magnets of the three upper switches which short-circuit sections of the resistor in series with the motor armature relay so that it does not release until the preceding contactor has closed its arcing tip has overcome this difficulty to a considerable extent. By winding the relay with a shunt coil and connecting it across a section of the starting resistance, the same results are obtained as by using the straight series coil and the relay may be readily over-magnetized without any additional contacts or connections.

The lockout contactors now in use are of several different designs. Prior to 1903 a contactor was placed on the market having two coils. In the off position the contacts were open. When the circuit was energized one of the coils lifted a plunger latch and released the contact, which however was prevented from closing by a second series magnet coil. This arrangement of lockout switch is used successfully today.

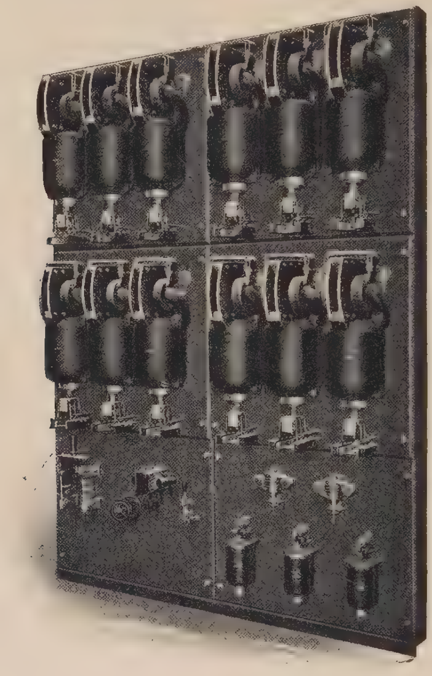


Fig. 22. D-c. Automatic Controller for Mine Hoist

This controller was built about 1906 and provided for the automatic operation of a 500-h.p. d-c. motor connected to a mine hoist

The more common type of contactor depends upon the saturation principle. There are two paths for the magnetic flux, one being the closing path and the other the lockout path. A part of the magnetic path in the closing circuit is of small section so that it becomes saturated at high current values. This permits the parallel or lockout path to predominate when the contactor is held open. When the magnetism decreases to a fixed value, the closing magnetism predominates and the contacts are brought together. If the current drops too rapidly the ampere turns in the closing circuit are not sufficient and the contactor fails to close. This is one of the chief drawbacks to this type of switch. A further description will be found in a subsequent chapter.

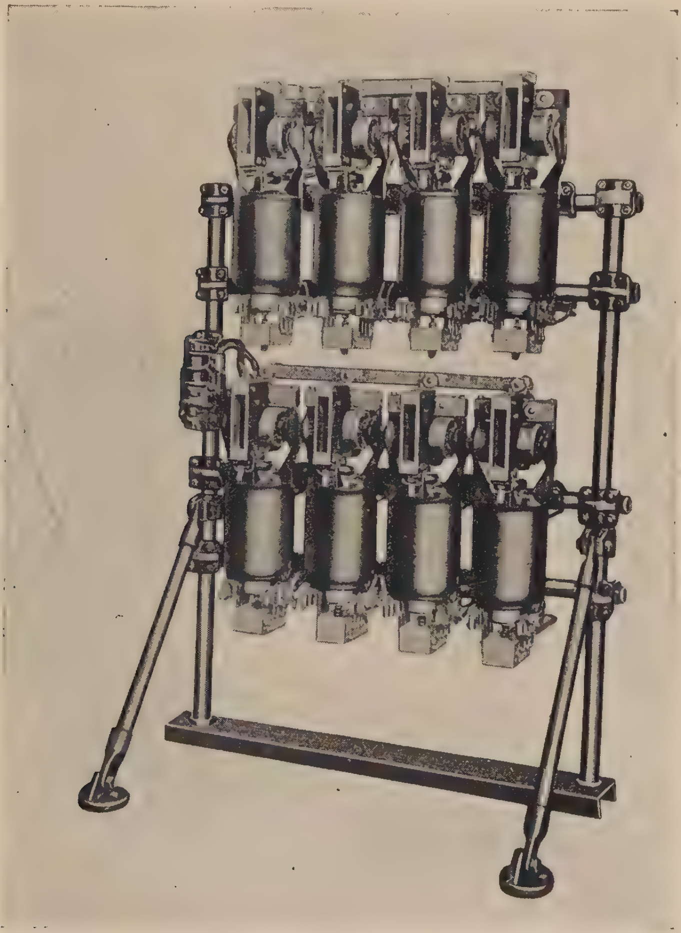


FIG. 23. D-c. Automatic Controller

This photograph shows a construction which eliminated the use of slate panels. It made a lighter controller and one that was more accessible. It was in use about 1908

Future Developments

The introduction of the electric motor for driving machinery has been revolutionary and is perhaps the most important factor in a high rate of production. At first it was necessary to build the motor and controller and demonstrate that it would drive a given piece of machinery and manipulate it in the desired manner. The development of the electric drive has required a broad experience and the co-operation of many minds. It was necessary to educate the users of machinery in the advantages of the electric drive. In this way co-operation was obtained between the engineers who design the motor and controller and the engineers responsible for the driven device.

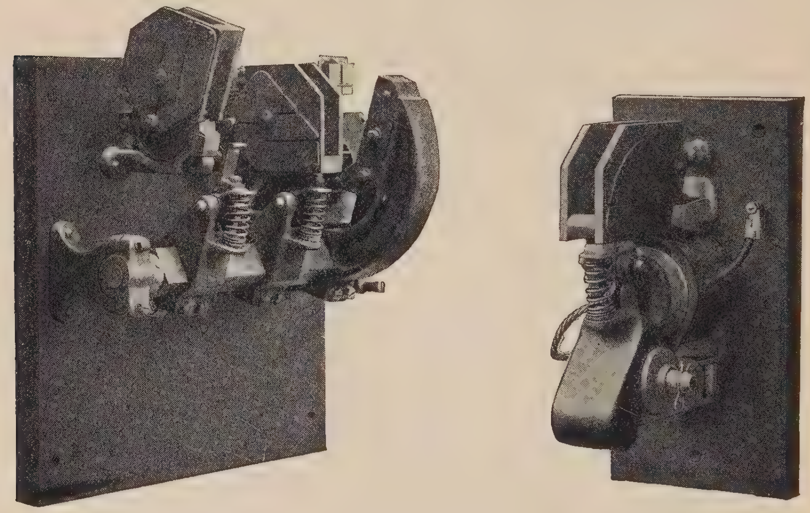


Fig. 24. Modern Contactors

This shows one form of the modern contactor, one of these being for d-c. and the other for a-c. circuits. Note that the form of magnet has changed from the coil and plunger type to the clapper type

As the application extended many special problems were met and solved. It was found that the requirements for many applications were very similar so that gradually the line of standard controllers and motors was developed and placed on the market. In making new applications, standard electrical apparatus was used where possible but many installations still required special apparatus, particularly controllers. Early designs of controllers were made complicated by extensive interlocking of parts which was later found unnecessary due to the greater reliability of the apparatus. This in turn simplified the controller.

At first the satisfactory operation of the electric drive was the foremost consideration. After this was established, questions of efficiency, first cost and maintenance received greater attention. Controller engineers have worked from the solution of a general problem to study in greater detail the different phases of the problem. The general form of contactor design is pretty well established. Further investigations are being made to improve the arc rupturing properties and to increase the temperature which the operating coil will withstand.

It is always dangerous to predict what trend future development will take. It is, however, safe to look a little distance into the future and to indicate some of the important lines along which work is now being done. One of these is the question of overload protection. The art needs devices which will protect motors and motor feeders against continuous overloads but will permit short time peak loads to be carried without interrupting the work. A satisfactory device of this kind will enable smaller feeder wires to be used to the motor and will reduce the number of burnouts in motors due to continued overloads.

Controller design is being influenced very rapidly by the question of personal safety to operators and other persons. This is discussed more fully in Chapter III. Electric controller practice is being standardized with very good results. We have had standard motor specifications for a number of years but until recently very little attention has been paid to standardizing requirements, sizes and performance of controllers.

SUMMARY OF CHAPTER II

Earlier Forms Manual: The earlier controllers were operated manually. A starting rheostat merely started the motor, a reversing controller provided also for reversing its rotation, and sometimes controlled the speed. Of the types evolved the bulky commutator or grindstone type is not made at present but the face plate, drum, and cam types are all in modern use, arranged both for hand and pilot motor operation.

Developments Due to the Application: Modern types have been influenced by their use in particular applications, for example:

Electric railways have dealt mostly with the series-wound motor and the drum controller. In the latter the design and material of the finger were changed to avoid stubbing, the finger base was changed from wood to insulated metal, a magnetic blowout was added to extinguish the arc, the copper segment contacts, at first mounted on a wooden cylinder, were attached to supports clamped to an insulated metal shaft and one design (cam controller) employed a cam shaft operating individual contactors. Since trolley cars were made with two or four motors, it was found that the motors could be connected in series to obtain a high torque at starting and then in parallel to obtain a high running speed (series parallel control). When cars were connected in trains, pilot motors were used to obtain centralized control, but the general use of compressed air on cars made possible the substitution of electrically controlled air operated devices (electropneumatic contactors).

Elevators used mostly shunt-wound motors, usually compounded at starting. Difficulties with the first hand rope operated control caused the adoption of magnetic contactors. Because of wear and sticking, the early coil and plunger type was succeeded by the clapper type. Three methods of accelerating the motor were devised, one depending for the closing of the accelerating contactors upon the rise of the counter e.m.f. of the motor (counter e.m.f. method), a second upon the falling of the starting current (current limit, subdivided into the relay, and the lockout contactor, method), and a third upon definite time devices (time element relay method). It was with elevators that controlling the speed by varying a resistance in the field circuit of the motor was first tried (adjustable speed motor). Using also resistors in series and in shunt with the armature gave a total of three operating speeds.

Machine tool requirements resulted in the further development of the adjustable speed d-c. motor and control and in the evolution of the reversing planer (slow forward, quick return, speed) motor and its controller.

Steel mill auxiliaries required series-wound motors and controllers of especially rugged design.

Automatically controlled machinery: Here the magnetic contactor, though more expensive, was found preferable to manual control because it gave quicker and more positive action, made possible more complicated sequences of operations, and increased production by the elimination of personal fatigue. Individual bases for contactors, at first useful when repairs were necessary, were dispensed with as the contactor became of more durable and reliable design. The number of electrical interlocks used in early types has been greatly reduced. At first only one current limit relay was used on a controller, being transferred through interlocks to each accelerating contactor in turn, but eventually it was found preferable to use a separate relay for each contactor to eliminate the interlocks.

Future Developments: Surveying broadly the history of control, it is noted that it has been necessary to educate industry to the use of electric drive and control. At first satisfactory operation of the apparatus was the object striven for, but later efforts were turned toward standardizing design, simplifying systems, decreasing costs, and the future looks also to improvements in arc rupturing, greater permissible temperature of coils, a longer time element overload relay, and greater safety to operators.

CHAPTER III

NATIONAL CODES AND INSTALLATION REQUIREMENTS

Two codes—National Electric Code, fire protection—National Electric Safety Code, for personal safety

Two codes have been issued covering the installation of electrical equipment; one has to do with fire protection and the other with safety to persons. Because control apparatus is the medium through which persons operate electric equipment and also because of its function of arc rupturing, this class of apparatus requires particular attention from both the fire and safety standpoints and some knowledge of these rules is necessary for a proper understanding of the controller problem.

FIRE PROTECTION

The National Board of Fire Underwriters has issued a set of rules known as the National Electric Code. The Factory Mutual Insurance Companies have issued the same code with additional explanatory notes under the subject of Rules for Electric Light and Power Equipments. The National Electric Code rules comprise a set of regulations that must be followed when making electric installations if such installations are to be approved by the fire insurance companies. These rules are the results of many years of experience and a large amount of research work. The National Board of Fire Underwriters maintains laboratories for research and testing. Apparatus tested by the board and meeting its requirements is listed in a publication of approved apparatus. The rules and publications can be obtained on application to the respective issuing bodies.

These rules have done a great deal of good in this country toward eliminating hazardous and flimsy construction in the design of electric apparatus and have afforded one of the incentives to maintain a high standard in electric apparatus. Any national set of rules exacts the same requirements from every manufacturer and purchaser and when properly formulated is fair to all and a benefit to the industry. Electrical engineers connected with manufacturing companies and customers' engineers responsible for applications have co-operated with the Underwriters in the formation of these rules so that they represent the best combined thought in this country on the subject.

SAFETY RULES

The question of the personal protection of employees and the general public has received very active consideration in the last few years. In 1916 the U. S. Bureau of Standards issued for trial a National Electric Safety Code, known as their circular No. 54. This was the first serious attempt made in this country to formulate a safety code for the purpose of standardizing the design and installation of electrical equipment. Since that time the casualty companies, manufacturers, and the National Board of Fire Underwriters have joined with the Bureau of Standards for the purpose of formulating additional rules. These various bodies organized the National Electrical Safety Conference in 1919 and have been active in this work.

The question of safety to persons may be considered with reference to three classes:

(1) The qualified person. This includes inspectors, repairmen, and electricians charged with the installation and maintenance of electrical apparatus.

(2) Operators.

(3) Other persons. This classification includes the general public and all workmen or employees in an industrial establishment who are not directly charged with either the maintenance or operation of a particular electrical equipment.

The question naturally arises as to who is a qualified person. At present any manufacturer or owner may employ and authorize a person or persons to install, inspect and maintain electrical equipment. It is probable, should an accident occur, that the employer would be called upon to show that he had exercised care in the selection of such employees. In the future, legislation may require such persons to pass an examination and be licensed for this work.

Injury from electrical apparatus may result in a number of ways, the more common being as follows:

(1) Touching live parts.
(2) Arc or flash.
(3) Touching hot parts.
(4) Explosion of fuses.
(5) Gas or dust explosions.

(6) Injury from moving parts of controller.
(7) Phase reversal.
(8) Unexpected starting.
(9) Overspeed.
(10) Lack of emergency stop.
(11) Overtravel.
(12) Failure of power.
(13) Overload.

Most of these hazards are avoided by the proper design and installations of the electrical equipment.

The two hazards which most often result in accident are touching live parts and arc or flash. The arc or flash may injure a person by direct burning or by exposing his eyes to the rays of the arc. They are familiar to most electrical engineers.

There are three general methods of guarding against the first six hazards mentioned:

(1) Enclosure.
(2) Isolation.
(3) Guards.

The use of enclosures for all electrical apparatus is rapidly extending. In industrial plants the controller and switching mechanism will often be found protected by cabinets or other suitable means. I believe that we will soon use covers over the commutators and brushes of motors. All electrical connections should be made by means of conduit. These enclosures, of course, add something to the first cost of the equipment but when properly designed, the cost is not out of proportion to the results obtained. Even where state or local laws do not require this protection, we must never forget that our industrial workers are human beings and of varying ages, and that many of them have the instinctive curiosity of youth and are inclined to investigate any apparatus which they do not understand.

Apparatus may be isolated so that it is accessible to qualified persons only, by one of the three following methods:

(1) Installed in a separate room with a locked door.

(2) Installed on a balcony, gallery, or platform so elevated and arranged as to exclude other persons.

(3) Elevated at least eight feet above the floor line or working platform.

The first method is used for large motors, generators, and switchboards where the expense of a separate room accessible only to authorized persons is justified. The other two methods are used for small motors and controllers installed about a manufacturing plant.

Electrical apparatus may be guarded by partitions, screens, fences or rails, so arranged that qualified persons only may have access to the space within reach of the electrical apparatus. This is a convenient method of protecting large switchboards or control panels and also large motors and generators where a separate room can not be readily provided.

The National Electrical Safety Code gives a very full and complete discussion of the various forms of hazard and protection against such hazard. This Code does not go into sufficient detail for working purposes. It is, therefore, necessary to supplement this work with more detailed description and rules.

Grounding: In most cases the enclosure of the controllers or the frame of the machine should be grounded. This requirement is obvious to those versed in the art. The exception to grounding is where the apparatus is accessible only to qualified persons and where insulating mats, platforms, or floors are provided surrounding the apparatus. In such cases no grounded parts should be within reach of the person working on the electrical equipment.

Disconnecting Means: It is recognized that all electrical equipment requires inspection, adjustment and some repairs, such as renewals of brushes, contacts, etc. In order to make it safe for a qualified person to perform this work, provision should be made for entirely disconnecting the apparatus from the source of electrical supply.

Where this disconnecting means is not within sight of the person working on the apparatus, means should be provided for locking it in the open position. This is usually done by a padlock. This requirement is also necessary where the apparatus driven by the motor is undergoing repairs or adjustments. Accidents have resulted from the unexpected starting of a conveyor or other machinery when a workman was repairing it.

Working Space: In installing electrical apparatus, suitable working space should be provided and maintained about the equipment. Where a motor or controller is mounted above the floor level, a suitable platform or other means of access should be provided. This is only a common sense requirement but is often overlooked.

The unexpected starting of a motor frequently results in accidents. This can usually be guarded against by the proper design of control equipment. Low voltage protection can be provided to prevent unexpected restarting after a failure of power. The controller handle may be either removable or provided with a latch or lock in the off position. The controller handle may catch in the clothes of a person working around this apparatus or it may become entangled in other apparatus being drawn by on trucks, etc., and the motor be started unexpectedly. A latch will prevent this.

All control apparatus should be so arranged that the circuit to the motor will be opened and remain open in case a pilot wire or contact should fail. The only safe arrangement of a protective circuit is to permit operation only while the circuit is intact. The breaking of a wire or failure of power from some other cause should stop the motors.

Location of Controller

It is desirable to have the controller located so that the motor and driven machinery will be in sight of the operator during the starting period. Where an arrangement of this kind is possible the operator can observe the apparatus during the starting period and if an accident should occur he can stop the motor promptly. Where the operator cannot be located so as to observe all of the machinery during starting additional precautions should be taken to protect persons who may be in or about the machinery at that time. For instance, stop buttons may be located at various convenient points which will enable some other person to stop the machinery promptly in case of accident. Another precaution would be to arrange the controller handle or the disconnecting means so that it can be locked in the open position by any person who might have occasion to work on the machinery and would be in danger if it were accidentally started.

Resistors

Resistors are used for the purpose of starting and regulating the speed of motors. Their function is to absorb electrical energy and dissipate it as heat. In order that they may function properly they must be provided with a reasonable amount of ventilation. This means that large units should not be located in a corner of the room remote from windows or in any other restricted position. This is particularly true of resistors used for regulating the speed of motors. Unless the motor is very large or is started very frequently, the energy stored in the resistor during the starting period is small and the ventilation in the case of resistors used for starting only is not so important.

Resistors should not be mounted close to combustible material. When mounted on the wall an air space should be left between the wall and the resistor. In general it is safe to consider the resistor as being a mild form of stove or other heating apparatus and take the same precautions with its installation as would ordinarily be taken in locating a stove or small heater.

SUMMARY OF CHAPTER III

Of two existing national codes, the National Electrical Code covers protection against fire and the discouragement of hazardous, poorly constructed apparatus, the National Electric Safety Code personal safety.

The latter distinguishes between qualified persons, unqualified persons, and operators. Examples of injuries or accidents causing injury are: touching live parts, injury from arc or flash, touching hot parts, explosion of fuses, gas or dust explosions, injury from moving parts, phase reversal, unexpected starting, overspeed, lack of emergency stop, overtravel, failure of power, overload.

Among the precautions that may be taken are: enclosure of apparatus, isolation of apparatus in separate room, balcony, or by elevating eight feet above the floor, guarding by partition, etc., grounding frames, providing means for disconnecting apparatus when making repairs, locking such means in the open position, providing ample clearance about apparatus, guarding against unexpected starting by low voltage or other device, utilizing make rather than break principle of control, locating controller in sight of motor and machinery, providing emergency stop buttons, care in locating resistors on account of heating.

CHAPTER IV

DESIGN DETAILS

Manufacturer responsible for design of details—factors of contact designs as to current carrying—three types of contacts—advantages of rolling contact—factors of contact design as to arc rupturing—magnetic blowout and arc splitter—rating of contacts—operating coils—supply voltage regulation.

THE detail design of controllers should be left to the manufacturer who guarantees their operation and satisfactory service. The application engineer must select the proper type and size of controller for each particular drive and he is therefore interested in knowing how variation in design may affect the performance of a controller.

The capacity of a controller to carry current with a given rise in temperature may often be of much less importance than the durability of the contacts under repeated arc rupturing, and the design of bearings to withstand wear in dirty places. A knife switch will carry current but will not last long if used for rupturing current. Current-carrying ability may be impaired by long periods of operation without opening and closing and the consequent scouring action on the contact surfaces.

When the controller is used infrequently and for short intervals of time, a much smaller controller can be selected than normal for the motor. An application of this kind would be a crane in a power house used only for repair work. For frequent operation, such as occurs with motors driving reversing tables in steel mills, the controller should be more than usually liberal. The continuous current capacity has little to do with either of these applications. If the motor drives a condenser pump in a power house, continuous current capacity is the most important consideration.

The essential requirements of a controller are current-carrying and arc rupturing. Means for opening and closing the contacts, while necessary, are of secondary importance to these two principal functions. Whether the contact is operated by hand, by a magnet, or by an air cylinder, it is important that it carry the motor current without injury and that it be able to interrupt repeatedly any ordinary overloads that may occur. In addition the mechanical parts must be rugged and able to stand the wear due to repeated operation.

FACTORS OF CONTACT DESIGN

Current Carrying

1. *The material from which made.*—Hard drawn or forged copper has given the best results.

2. *The Pressure between Contacts.*—Other things being equal, the heavier the pressure, the more current the contact will carry. There are, of course, limits to this pressure, but the carrying capacity can be materially enhanced with an increase of pressure.

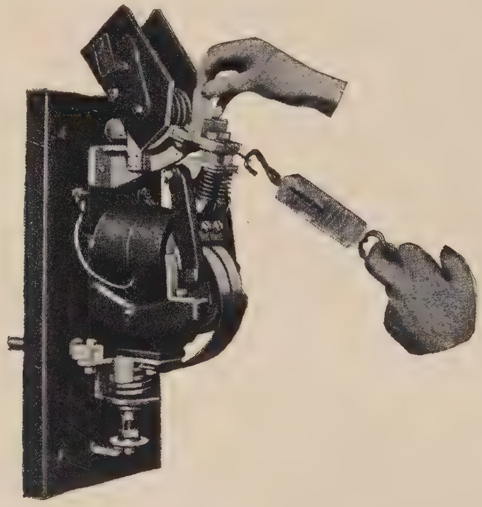


Fig. 25. Method of Testing Contact Pressure

3. *The Mass of the Contact.*—The greater the mass, the more heat carried away from the contact surfaces, and distributed through the adjacent material.

4. *Radiation.*—This factor determines the amount of energy which can be dissipated with a given temperature rise. With considerable mass in the contact, there is a greater radiating surface available for dissipating the heat.

5. *The Surface of the Contact.*—The surface should be clean and free from the oxide scale which forms when the arcing takes place in the air. This oxide is a non-conductor and interferes with the passage of current. Arcing under oil results in more or less of a carbon deposit which is a conductor, although it may not be as good a conductor as the original material. Usually the design of contactor will give a small amount of

wiping action which cleans the contact surfaces when the contacts are being closed. This sliding or wiping action wears away the contacts, and should be limited to a very small motion.

Types of Contacts

Contacts are usually of three general types:

1. *The Butt Contact.*—An example of this is the laminated copper brush.

2. *Sliding Contact.*—An example of this is the drum controller using fingers sliding on a cylindrical surface.

3. *Rolling Contact.*—This form of contact is the most reliable and most satisfactory now in use. Contact is made at the tip and rolls down the surface to the heel. (Figure 26.)

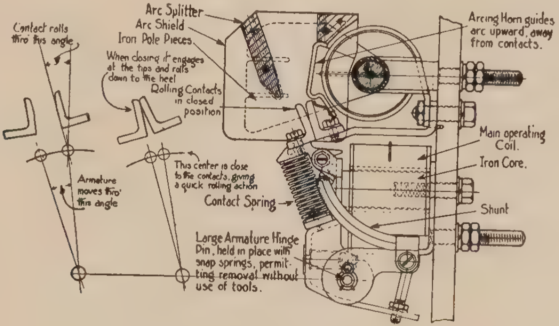

Contact rolls thro' this angle
Arc Splitter
Arc Shield
Iron Pole Pieces
When closing it engages at the tips and rolls down to the heel
Rolling Contacts in closed position
Arcing Horn guides arc upward, away from contacts.
Main operating Coil.
Iron Core.
Armature moves thro' this angle
This center is close to the contacts, giving a quick rolling action
Contact Spring
Shunt
Large Armature Hinge Pin, held in place with snap springs, permitting removal without use of tools.

Fig. 26. Action of Rolling Contacts

Usually the movable contact member is attached to the armature of the magnet and mounted on an auxiliary pivoted member designated as the contact support. The pivot of this contact support approaches the stationary contact through the arc of a circle and the movable contact is tilted forward so that its tip comes in contact with the stationary contact tip. The further movement of the magnet armature causes the movable contact to roll against the stationary contact until the heels or bottom parts of the contacts are in engagement. An important part of the design is the relation between the pin around which the contact support rotates and the position of the contacts. The action of the contacts against each other cannot be a true rolling action, as the contact support hinge pin rotates through a circle and therefore its center moves up and down, due to this rotating action. The rolling action is therefore combined with a small amount of sliding action. The least amount of sliding is obtained when the moving contact center is located so that it moves an equal distance on either side of the line drawn from the heel of the contact to the armature hinge pin. Even with this arrangement of centers there is always sufficient sliding action to keep the contact clean. Excessive sliding action causes additional mechanical wear on the contact and in this way reduces their life. An endurance run on contactors having different amounts of sliding action makes the results of this wearing away of the contacts very evident.

Excessive sliding action is also disadvantageous from another point of view. If the surfaces of the contacts become rough, they have a tendency to lock together and prevent the sliding action. While this locking together is not absolutely positive, it has been found sufficient, in cases where the sliding action is excessive, to prevent the armature of the magnet from closing.

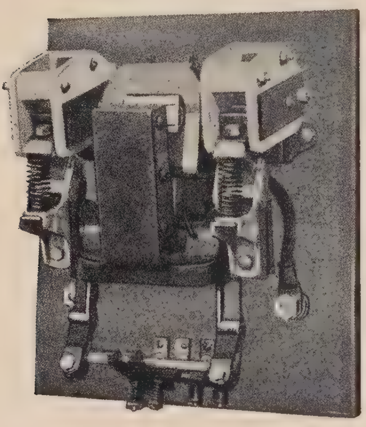


FIG. 27. Two-pole A-c. Contactor with Interlocks

When a magnetic contactor is closed the contacts strike together with considerable force and there is a slight rebound. When the contact rebounds, it draws a small arc which softens the surface of the contacts at the point where they touched. If these contacts are permitted to come together at the same point after the rebound, there will be a decided tendency to weld or freeze, due to the softened metal parts coming into contact. This re-establishment of contact at the same point is prevented by the closing movement of the magnet armature. During the period of rebound, the armature has travelled closer to the magnet core and the center carrying the contact support is in a new position, so that contact is re-established at another place. This action was very nicely illustrated by a test. A magnetic contactor was connected to full load with a large condenser across the terminals. As a condenser produces a heavy discharge at the instant a contact is established, this property is frequently used for the purpose of welding small wires together. A condition was thus established which would materially increase the chances of welding at the instant of contact. The fact that this condition actually existed was demonstrated by closing the contacts slowly, which caused them to weld readily. When the contactor was closed by the action of the magnet, although a large number of operations were made, not a single weld was obtained, the rolling action being sufficient to prevent welding.

The closer the center of the contact support is to the contact, the greater the lever action exerted by the closing means and therefore the greater ease with which a welded contact may be broken apart. This is of particular value in connection with manually-actuated contactors, as these are more likely to be welded, due to improper operation. If the contact is closed by a cam, or lever, the operator can exert a very powerful force to break open any ordinary weld.

Advantages of Rolling Contact

The advantages of the rolling contact can be summarized as follows:

(1) The current is carried at the heel of the contactor. This is kept clean by a slight sliding motion during the closing period. The contact at this point is under the maximum spring pressure.

(2) The arcing takes place at the tip of the contact, as this is the last part of the contact to separate.

(3) The rolling action minimizes the bounce upon closing.

(4) When the contacts are properly operated they will not weld.

(5) The absence of any considerable sliding action prevents the contact from sticking if the surfaces become roughened.

(6) Heavier pressures can be maintained between the contact surfaces than where sliding contacts are used. The pressure is limited to about 10 lbs. per lineal inch for sliding contacts, on account of the cutting action.

Arc Rupturing

The design of contacts to rupture current depends upon the following items:

1. Shape of contacts.
2. Size of contacts.
3. Material from which contacts are made.
4. Separation of contacts when opening.
5. Speed of opening.
6. Strength and distribution of magnetic blowout field.
7. Design and size of arc box.
8. Material from which arc box is made.

All of these items have their effect on the maximum rupturing capacity of the contacts and the durability of contacts and arc box under severe service. The greater the energy handled the larger must be the arc rupturing means and the more important it is to consider these various items in detail. The design engineer has at his disposal a certain amount of exact information which is supplemented by experience and test data. The exact determination of all these items involves many factors on which complete information is not now available.

A general understanding of what takes place when an arc is ruptured can be obtained by a brief description of the action in the arc box.

The arc may be considered as consisting of a stream of positively and negatively charged gaseous particles or ions that travel rapidly from one contact to the other. This stream of rapidly moving ions constitutes the arc current between the contacts. Since it is a flexible conductor it can easily be stretched out lengthwise or readily deflected. If a transverse magnetic field is applied to this conductor the reaction between the conductor and the field will be similar to the action which takes place in a motor where a conductor carrying current is placed in a magnetic field. The conductor moves in the same direction as it would in a motor. This movement increases its length, which cools the arc gases and increases the resistance to the flow of current. The increased length makes it more and more difficult for the voltage across the arc to maintain the flow of ions, until finally the arc is ruptured. The length of the arc depends upon the amount of current flowing when the arc is established, upon the voltage between the contact and upon the stored energy in the circuit. The length of this arc may readily be influenced by the design of the arc box and blow-out field.

In addition to the ions which make up the flexible conductor, some stray ions accumulate in the arc box. If the distance between the contacts is small, the voltage between the contacts may cause these stray ions to re-establish the arc by forming a new flexible conductor. Oscillograph records show that sometimes the arc is re-established two or three times before it is finally interrupted. The re-establishment of the arc depends upon the design of the arc box and the separation of the contacts. The higher the voltage, the greater the separation required. If two contactors are used in series, there is much less liability of the arc re-establishing itself. The two breaks in series also assist in rupturing the arc, as they require the maintenance in series of two flexible conductors made up of ions. They also distribute the heating effect between two or more arc boxes.

To rupture an arc, it is necessary to lengthen the arc path, so as to increase the resistance, and therefore decrease the current, and at the same time, to cool the arc. The contacts should also be separated far enough to prevent a re-establishment of the arc, or two or more breaks should be used in series for this same purpose.

MAGNETIC BLOWOUT AND ARC SPLITTER

The cooling of the arc vapor and lengthening of the arc path is usually accomplished with a magnetic blowout. This lengthening and cooling may be materially assisted by interposing barriers or arc splitters in the path of the arc, Fig. 28.

The ions, which maintain this arc stream, are not only cooled and discharged by contact with the sides of the arc box and the surrounding air, but are also cooled by coming in contact with these arc splitters. The length of the arc is also materially increased while it is still under the influence of the blowout field, by stretching it across these arc splitters. The projection or throw of the arc beyond the edge of the arc box is therefore decreased and much greater energy can be broken in the same size of arc box. If the arc extends a considerable distance beyond the edge of the arc shield, it ceases to be under the influence of the magnetic field and may continue to hang on for an appreciable length of time. The burning on the contacts and arc box for any given current depends upon the length of time the arc is maintained. The further the arc must travel in order to be ruptured, the greater the time of burning. By using these arc splitters, the arc is extinguished more quickly and therefore the amount of burning is decreased.

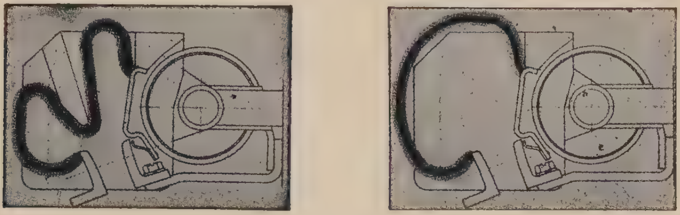


FIG. 28. Cross-section of Switch Illustrating Path of Arc with and without Arc Splitter

The material of which the arc shield is made bears an important relation to the duration of the arc. Many asbestos compounds, now in the market, contain a binder, which is fused by the arc and forms a conducting skin on the side of the arc box. Tests made with certain well-known asbestos compounds showed that after the arc has been ruptured several times, the time of rupturing was materially increased, the amount depending upon the design of the box. It is therefore very desirable to construct arc boxes of a material which does not form this conducting skin. The more refractory the material, the greater the life of the arc box. In a number of cases carborundum has been molded in the arc shield directly opposite the contact but it is not a good insulator and cannot be depended upon alone for the necessary insulation in high voltage boxes.

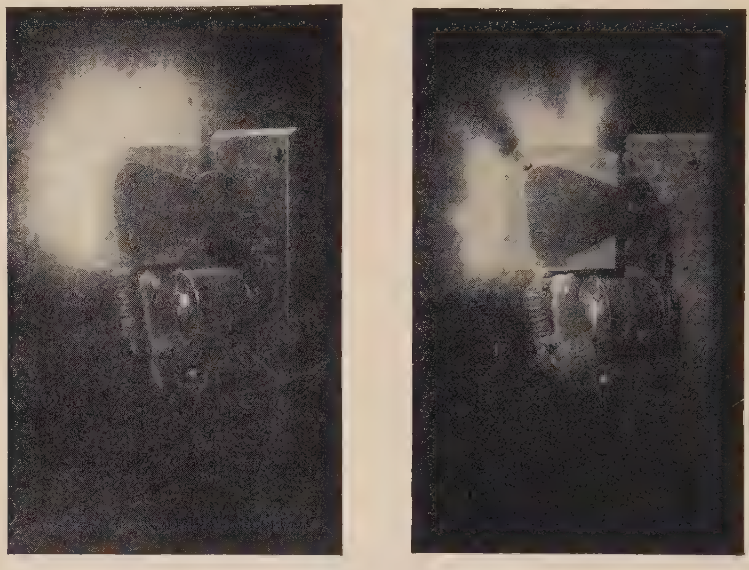


FIG. 29. Action of Arc Splitter

An illustration of contactors with and without arc splitters is shown in Fig. 29. It is difficult to obtain photographs of this kind which correctly represent what takes place when a current is ruptured but the illustration will serve to give a general idea of the way in which an arc splitter works on a relatively small contactor.

An interesting test is illustrated by the oscillographs, Figs. 30 and 31, which are the results of tests made on a 6600-volt contactor with magnetic blowout. The first test shows the contactor rupturing a 3000-volt direct-current circuit of 750 amperes maximum and with an inductance of 23 millihenries. The second oscillograph, Fig. 31, shows the same contactor rupturing a 6600-volt alternating-current circuit of 950 amperes and a 60 per cent power factor. In the first test a single contactor was used but in the second test two contactors were used in series. As the maximum voltage between contactors in the a-c. circuit was in the neighborhood of 10,000 volts, which is over three times the voltage obtained on the d-c. test, two contactors in series were necessary in order to obtain the required separation between contacts and prevent the re-establishment of the arc.

In testing a-c. contactors a circuit in the neighborhood of 50 per cent power factor or less should be used as this gives the most difficult conditions. It is much easier to rupture current on circuits of 100 per cent power factor as the current passes through zero at the same time the voltage is zero and the arc is not easily re-established. On the other hand with a low power factor there is a considerable voltage between the contacts at the instant the current passes through zero and therefore a re-establishment can more readily take place.

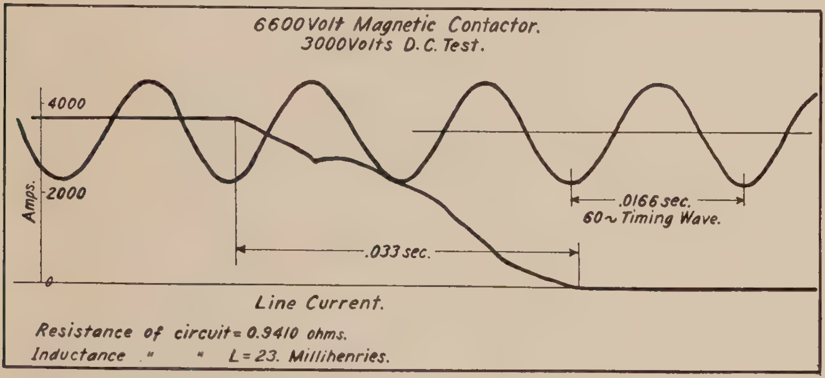


FIG. 30. Action of 6600-Volt Magnetic Contactor

Tested with a 3000-volt direct-current short-circuit. Resistance of circuit, 0.941 ohm. Inductance of circuit 23 millihenries

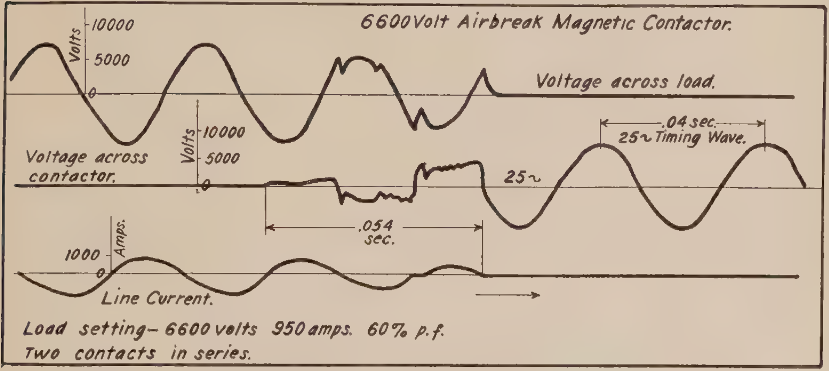


FIG. 31. Action of 6600-Volt Air-brake Magnetic Contactor

Tested with two contacts in series on 6600 volts, 950 amperes, 60 per cent power-factor

Where a large motor is started and stopped frequently, such as in hoist service, it is preferable to use an air break contactor. An oil immersed contactor forms carbon in the oil each time the circuit is broken; an accumulation of this carbon will ultimately interfere with the proper operation of the contactor. Each time the arc is broken, the heat is transmitted to the oil, which in turn must radiate it from the outside of the case or tank. Repeated opening and closing will very materially increase the temperature of the oil, so that it is necessary to have a tank of proper proportions to absorb and radiate this energy without raising the oil to a dangerous temperature. These limitations have usually led engineers to prefer the air break contactor for frequent operation.

Rating of Contacts

The method of rating contacts depends entirely upon their service requirements. Two general methods are followed:

1. Rating on a basis of a continuous ampere capacity.
2. Rating on a basis of durability.

Where the load on the contacts is continuous, the temperature rise under load conditions is an important item. In many cases, however, the wear on the contacts is severe and a much larger contact is used than would be necessary for continuous carrying capacity.

Operating Coils

The temperature of operating coils on magnetic contactors is affected by:

1. Variation of line voltage of the magnetic air gap, and by variation in frequency on a-c. circuits.
2. Variation of the air temperature, ventilation, moisture in the air, etc.
3. Variations in the load on the current carrying parts of the contactor. Heat is readily transmitted from one part of the contactor to another, so that local heating in some other part of the contactor may materially affect the temperature of the operating coil. Sometimes the use of a small lead wire to a contactor will make considerable difference in the temperature of the contacts and operating coil.

The rating of contactors or other control apparatus is affected by an enclosing case or cover. Any restriction in ventilation increases the temperature and this is particularly true for control apparatus where the speed regulation of the motor is obtained through the use of resistors. Care should always be exercised in locating heat-producing apparatus, so that proper ventilation will be obtained.

REGULATION

A variation in line voltage has a bad effect on control apparatus. A decrease in voltage may cause difficulty in the closing of contactors or the operation of other magnetic devices. An increase in voltage will cause overheating in shunt coils. If a motor is operating at a given voltage and this voltage is suddenly decreased below the counter e.m.f. of the motor, the current through the motor will be reversed and generator action take place. A small difference of voltage is sufficient to cause a heavy flow of current if the motor is connected directly to the line without external resistance. This not only causes a jolt in the motor, but it is very bad on the drive. If gearing is used, the back lash in the gearing may cause a serious blow to the teeth, and in many cases, gears have been stripped in this way. If a chain drive is used, the results are even worse. Successful operation of electric drive depends upon a reasonably steady voltage; rapid fluctuations of the voltage are particularly harmful.

SUMMARY OF CHAPTER IV

DESIGN OF DETAILS: The manufacturer primarily is responsible for the design of controller details, but the application engineer selecting the type and size of controller for an individual application is interested in knowing how variations in design affect performance. The importance of details is relative: for a condenser pump in a power house continuous current carrying capacity is vital; for a reversing table in a steel mill, durability to withstand arc rupturing is essential; for a crane in a power house, used only for repair work, a smaller controller than normal would be satisfactory. The rating of contacts depends, therefore, upon whether durability or continuous capacity is most desired. In general, a controller must carry the current, rupture the arc, be reliable of operation, and withstand mechanical wear.

CONTACTS: Hard drawn or forged copper for contacts has given the best results. Within practical limits, the greater the pressure holding the contacts together the greater the current they will carry. The greater their mass and surface the greater their capacity to radiate heat.

Arcing in air causes an oxide scale. To free the contact surface of this the contactor should be designed to give a small amount of sliding action between contacts. To reduce wear and to prevent the contacts from sticking when roughened, this sliding action should be kept to a minimum.

Contacts may be butt (for example, the laminated copper brush), sliding (finger on drum), or rolling. The latter is the most reliable. The movable contact member moves through the arc of a circle with its pivot as a center and pivoted on the circumference of this circle is the movable contact, which also moves through the arc of a smaller circle. A combination of rolling and sliding action results. The contacts touch first at the tip; the movable contact then partly rolls, partly slides, down the surface of the stationary contact until the heels are in engagement. When the contacts first touch there is a slight bounce, but during the rebound the magnet has drawn the armature closer so that the contacts engage at a new point on their surface and freezing or welding is prevented.

Advantages of Rolling Contact:

1. Current is carried at the heel of the contact. This is kept clean by a slight sliding motion during the closing period. The contact at this point is under the maximum spring pressure.

2. The arcing takes place at the tip of the contact as this is the last part of the contact to separate.

3. The rolling action minimizes the bounce upon closing.

4. When the contacts are properly operated they will not weld.

5. The absence of any considerable sliding action prevents the contacts from sticking if the surfaces become roughened.

6. Heavier pressures can be maintained between the contact surfaces than when sliding contacts are used. For sliding contacts the pressure is limited to about 10 pounds per lineal inch, on account of the cutting action.

Extinguishing the Arc: The arc current, a stream of positively and negatively charged gaseous particles of ions, flowing between contacts, being a flexible conductor, by means of a transverse magnetic field may be stretched, cooled, and its resistance increased, causing it to be quickly extinguished. An arc splitter confines the arc to the magnetic field and increases its length. Using another contactor to break the circuit at a second place renders it more difficult for the arc to reestablish itself. The arc box shield should be made of a nonconducting material. If asbestos is used the binder should not conduct when fused. In testing a-c. contactors a circuit of fifty per cent power factor should be used to give the most difficult conditions, to make certain the arc is not reestablished by the voltage existing when the current passes through zero.

Oil immersed contactors accumulate carbon deposits from breaking of the arc and heat the oil. For frequent operation, therefore, the air break type of contactor is preferred.

The temperature of a coil is affected by variations of the line voltage, magnetic air gap, frequency, current, air temperature and humidity, ventilation, size of lead wires to coils.

Enclosed apparatus that overheats in service should be ventilated.

The voltage should be steady. With too low a voltage the control apparatus may not operate, too high a voltage may cause overheating of coils, fluctuations may result in jolting of the driven machinery, with consequent harm to the gears.

CHAPTER V

HOW TO READ CONTROLLER DIAGRAMS

Diagram of starting rheostat explained—of starting rheostat with low voltage protection—of armature and field regulating rheostat—of nonreversing drum controller—of reversing drum controller—of magnetic contactor panel.

The present discussion is intended to deal, in an elementary manner, with a few simple forms of controllers, in an endeavor to explain some of the fundamental principles of operation. A thorough understanding of this section will be of material assistance in following subsequent discussions of more complicated forms of controllers as used in various industries.

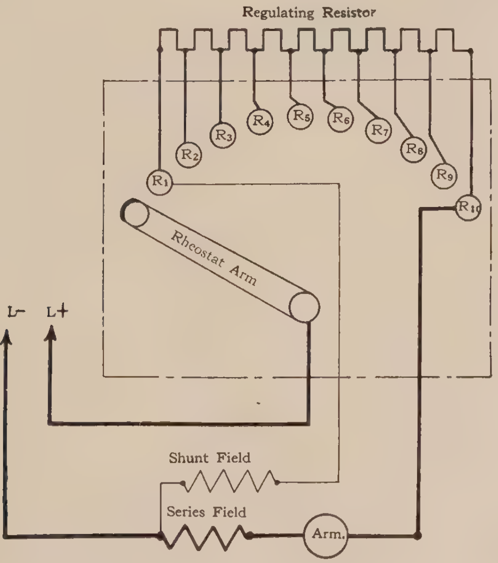


Fig. 32. Elementary Controller Diagram, with face plate rheostat

Face Plate Controllers

The face plate controller is the simplest type used for starting or regulating the speed of an electric motor. Fig. 32 illustrates the elements of this controller. While this arrangement is operative, commercial apparatus usually has additional features, which in this instance are omitted for the purpose of clearness. $L+$ and $L-$ represent the two power wires leading to the controller and a compound-wound motor. If the rheostat arm be moved from the *off* position, shown in the diagram, to the contact R_1, current will flow from $L+$ to the arm, from this to contact R_1, through the regulating resistance to R_{10}, thence through the armature and series field of the motor to $L-$. The shunt field is connected from R_1 to $L-$, and is energized as soon as the rheostat arm makes contact with R_1. The voltage across the armature will be equal to the line voltage minus the voltage drop through the regulating resistor. The torque of the motor will be proportional to the armature current and the field strength. When the contact is first made at R_1 the field strength is zero, and it takes a short interval for the field to reach its full value, so that under ordinary conditions the torque will increase from zero to a value which will start the motor. The rotation of the armature in the motor field generates a voltage known as the counter e.m.f. which opposes the line voltage. As the motor increases in speed, the difference between the line and counter e.m.f. becomes less and the motor current decreases until a balanced condition is reached. When this balancing condition is reached the speed of the motor may be further increased by moving the rheostat arm to contact R_2. Additional increments of speed are obtained by additional movements of the arm to other contacts until all of the regulating resistance is eliminated from the circuit and the arm *rests* on contact R_{10}. The arm should be allowed to remain on each contact until the motor reaches its balancing speed for that step of the resistance, so that the minimum amount of current will be taken by the motor.

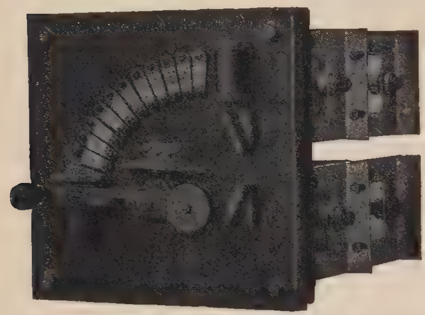


FIG. 33. Starting Rheostat of face-plate type, showing grid resistors

In bringing the motor to rest, the reverse operation of the arm is made. In passing from contact R_1 to the *off* position, the connection between the motor and $L+$ is interrupted, causing the motor to come to rest. The shunt field, however, will still be connected across the armature of the motor, including the regulating resistor. This connection should be used wherever possible, as it allows the field current to die down gradually as the speed of the motor decreases. The drop in voltage through the starting resistor, with only the field current flowing, is so small that it may be neglected and the field can be considered as having a voltage equal to the counter e.m.f. of the motor. The shunt field winding consists of a large number of turns of fine wire. Any change in the value of the field current is opposed by the self-induction of this winding, so that a change in the current should be made gradually. If an attempt is made to open the field circuit abruptly, the self-induction will cause a high voltage to build up between the terminals of the field coils, which may result in the breaking down of the insulation.

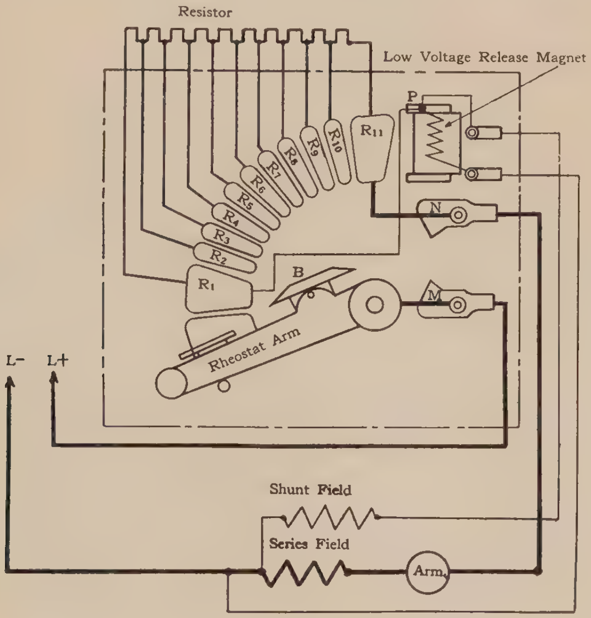


FIG. 34. Diagram of Starting Rheostat of the Type Shown in Fig. 33

If the rheostat is to be used for starting purposes only, the resistor is made of less current-carrying capacity than for regulating purposes. It is called a "starting rheostat," or a "regulating rheostat," depending upon the purpose for which it is used. The connections, however, are the same, the difference being only in the capacity of the resistor. A commercial design of starting rheostat is shown in Figs. 33 and 34. This rheostat differs from the one previously described, in the addition of the low-voltage release magnet. The rheostat arm is provided with a spring, which returns it to the *off* position if the handle is released during the starting of the motor. After the motor has been brought up to speed, and the rheostat arm rests upon contact R_{11}, the low-voltage release magnet holds the arm in this position. Brush B bridges between the terminals *M* and *N*, so that in the running position the current passes from *L* + to terminal *M*, through the brush *B* to terminal *N*, thence to the armature of the motor and through the series field to *L* —. This provides a parallel circuit to the one through the rheostat arm to contact R_{11}, so that the continuous flow of current will not overheat the rheostat arm and its contacts. In the running position the rheostat arm is held firmly by the low-voltage release magnet, so that current flows from *L* + through the rheostat arm to point *P* on the magnet. One circuit then passes through the magnet winding to *L* —. The other circuit is connected to the shunt field. If, for any reason, the line wires are disconnected or the voltage on the circuit fails, the low voltage release magnet will be de-energized and the spring will return the rheostat arm to the starting position.

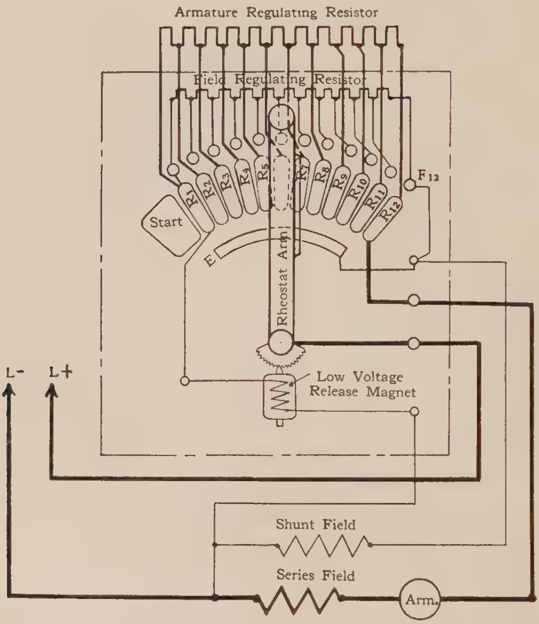


FIG. 35. Diagram of Starting and Regulating Rheostat, Having both armature and field resistors

A controller provided with both armature and field regulating resistance is shown in Fig. 35. The motor is known as an adjustable-speed motor, and can have its speed changed by adjusting its field strength. The rheostat arm is made in two parts, the under part making contact with the segments marked R_1 to R_{12} and with the contact ring *E*, while the top arm engages the upper row of round contacts. When starting the two arms are held together by a latch. The bottom arm is provided with a notched segment engaging a plunger forming part of the low-voltage release magnet. The notched segment and pawl hold the arm in any operating position after the low-voltage magnet is energized.

To start the motor, the contact arms are moved from the *off* position to contact R_1. The current flows from $L+$ through the arm to contact R_1, thence through the armature regulating resistor to contact R_{12}, and then through the armature and series field to $L-$. The shunt field current flows from $L+$ through the arm to the segment E, to the field windings and thence to $L-$. Connected with R_1 is a shunt circuit passing from the positive side of the line through the low-voltage release magnet to the negative side of the line. The arms are gradually moved to the right, eliminating successively each section of the armature resistor until the bottom arm makes contact with R_{12}. In this position the armature is connected directly across the line and the segment E disconnected from the rheostat arm. The shunt field circuit now is from the positive side of the line through the upper rheostat arm to the right-hand field contact F_{12}, thence to the field winding. This gives a motor speed corresponding to full field strength. If it is desired to increase the speed of the motor, the upper arm can be moved to the left across the field

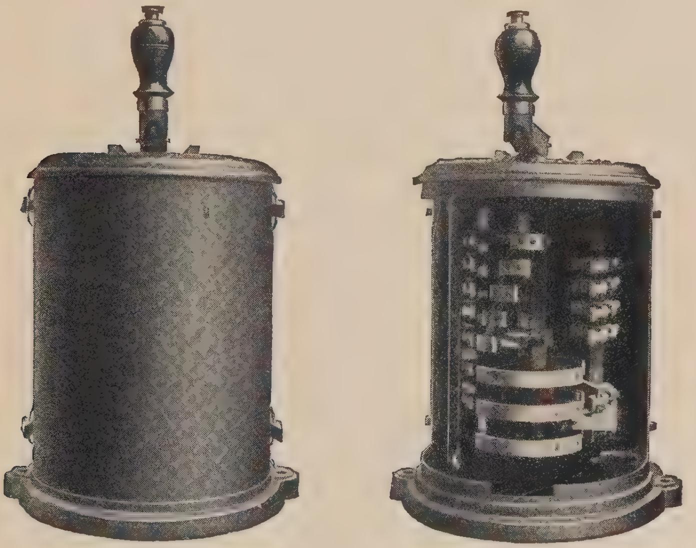


FIG. 36. Typical Reversing Drum Controller

contacts to insert resistance gradually in the shunt field circuit and thus within its range give the increased speed required, while the low-voltage release magnet holds the lower arm on contact R_{12}.

If the circuit is interrupted, the low-voltage release magnet will allow the lower arm to be carried to the *off* position by means of its spring. It, in turn, picks up the upper arm and the two are moved quickly to the *off* position.

Drum Controllers

A drum type of controller is shown in Fig. 36. Such a controller consists of two rows of contact fingers attached to the frame work of the controller, but insulated from it so as to be electrically separated from each other. Between these rows of fingers is mounted an insulated cylinder or drum, which is revolved by the handle. On this drum are mounted copper segments of different lengths which engage the contact fingers. The length and location of these segments are such as to make different connections for each "notch" of the controller. A drum, the controller box with contact fingers in position, and cover, are shown in detail in Fig. 37. Attached to the drum shaft at the top is a wheel having notches corresponding to each of the operating positions of the

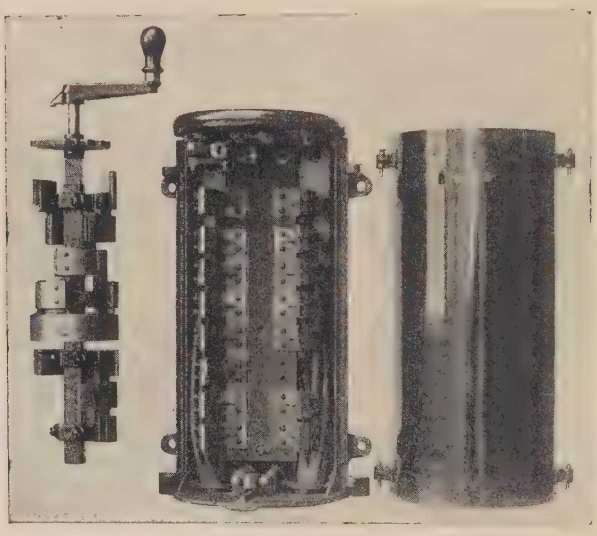


Fig. 37. Industrial Drum Controller

Showing drum, position of fingers in controller box, and cover controller handle. A roller is forced into one of these notches by a spring whenever a set of contacts is properly engaged, thus indicating to the operator the correct running positions of the controller and preventing motion from any of these positions, due to vibration or other accidental means. Fig. 38 shows the segments of such a drum as they would appear if rolled out flat. The two vertical rows of circles represent the stationary contact fingers. The horizontal strips represent the segments of the rotating drum, and the vertical dotted lines show the position of the segments with respect to the controller fingers at each successive position of the drum.

A slip-ring motor control arrangement with the controller connected only to the secondary circuit of the motor is shown in Fig. 39 with the drum rolled out or "developed" as in Fig. 38. When the primary of the motor is connected to the power line, current passes through the

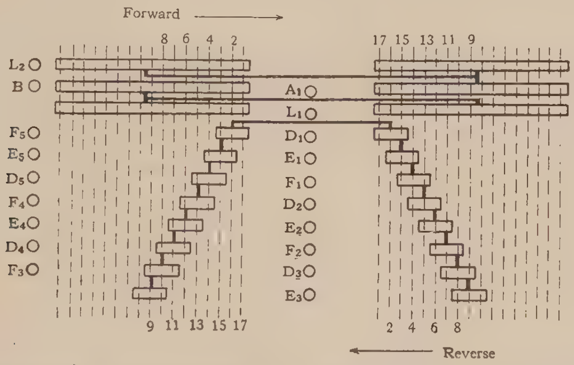


FIG. 38. Diagrammatical Representation of Drum and Contact Fingers Rolled Out Flat or Developed

secondary wires, and thence through the resistor, completing the circuit. When the motor is at zero speed the controller drum should be in position *1*. If the cylinder of the drum is now moved from right to left, the dotted line *2* travels over to the center line of the contact fingers and the resistor section E to E_1 is short-circuited, decreasing the resistance in part of the secondary circuit of the motor. As the speed of the motors increases, a further movement of the drum will cause the vertical line *3* to intersect the contact fingers. This will short-circuit the resistor section from D to D_1. At each increase of the motor speed a further movement of the drum may be made until the vertical line *13* intersects the controller fingers. In this position all of the resistor is short-circuited and the motor is operating at full speed.

A drum controller diagram similar to that shown in Fig. 39, except the line. The other two terminals of the motor, marked *A* and *B*, are connected to correspondingly marked terminals of the controller. In the forward direction, the drum segments on the right-hand side of the diagram move toward the left-hand row of fingers, and the segments on the that it provides for reversing the direction of rotation of the motor, is given in Fig. 40. One motor terminal marked *C* is connected directly to

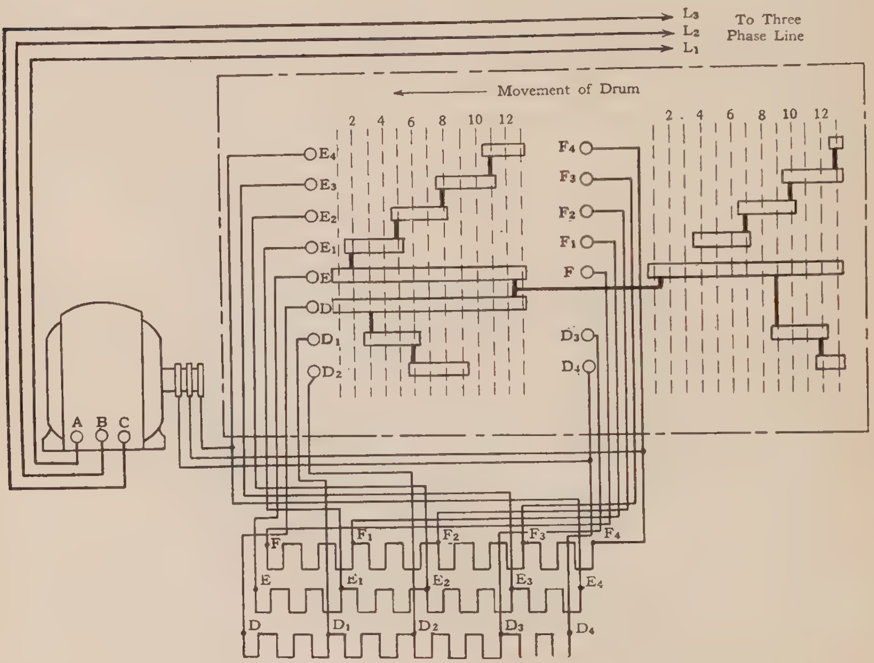


FIG. 39. Diagram of Non-reversing Controller

For three-phase, slip-ring motors, showing resistors and "developed" drum

left-hand side of the diagram move toward the middle row of fingers. This will be understood if the developed diagram showing the drum contacts is replaced so as to fit on the surface of a cylinder or drum and the contact fingers marked on two vertical sticks of wood mounted on each side of the cylinder 180 degrees apart. When the drum segments are moved from left to right for forward operation, the terminal *A* of the motor is connected through finger A_1, and the second and third segments from the top, which are connected together as indicated, to L_1 power wire. Likewise, the terminal *B* of the motor is connected to L_2 power wire.

The arrangement of the drum contacts for short-circuiting the secondary resistors differs somewhat from that shown in Fig. 39. The first notch in the forward direction closes the contacts to the primary of the motor A to L_1 and B to L_2. A drum segment is brought in contact with the finger marked D_1 on this notch, but as no other connection is made to the resistors this contact causes no change in the secondary resistance. The motor, therefore, starts to rotate at its minimum speed with all resistance in the secondary. When the drum is moved over until dotted line *2* intersects the central row of fingers, the one marked E_1 is connected to the drum, short-circuiting the section of resistor between D_1 and E_1. Next the dotted line marked *3* intersects the central row of fingers and F_1 is connected to the drum, short-circuiting another section of the resistor. This sequence is continued until the dotted line *8* intersects the central line of fingers connecting E_3 to the drum. A further movement of the drum causes the dotted line *9* in the right-hand part to intersect the left-hand row of fingers connecting resistor F_3 to the drum. The dotted lines *10* to *15* successively intersect the left-hand row of fingers, gradually short-circuiting all of the resistor, which brings the motor up to full speed.

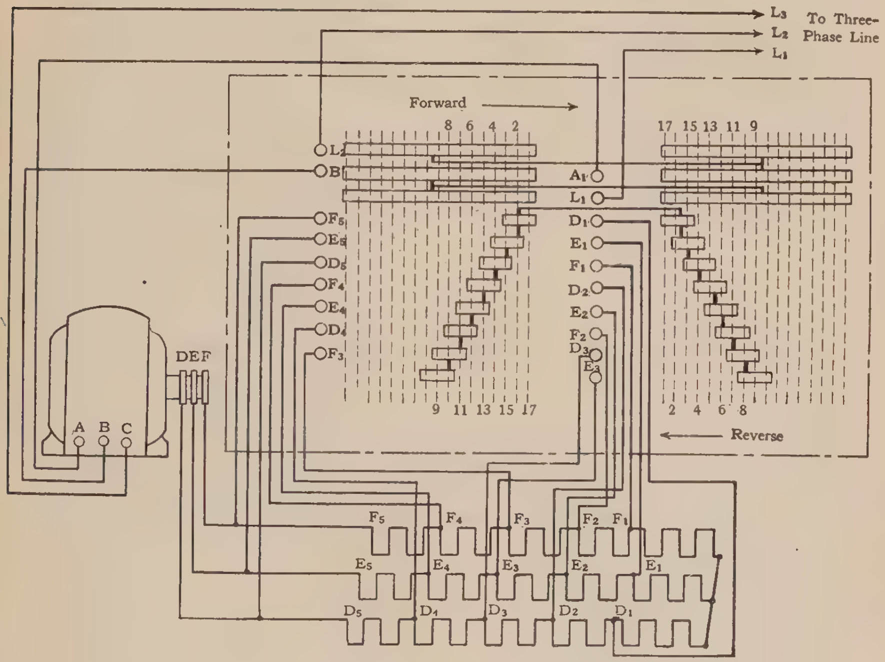


FIG. 40. Diagram of Reversing Controller

The reverse direction of operation causes the drum segments to move from right to left. In this case the left-hand dotted lines are brought into contact with the left-hand row of fingers and the right-hand row of dotted lines into contact with the middle row of fingers. The primary terminal A of the motor is connected to line L_2 and the terminal B of the motor to line L_1, when the dotted line *1* intersects the middle row of fingers. A further movement of the drum from right to left causes the dotted lines *2* to *8* to intersect successively the central row of fingers. This short-circuits a part of the starting resistors. Further movement of the drum from right to left causes the contact shown on the dotted line *9* to intersect the finger F_3. A further movement brings the dotted lines *10* to *15* inclusive, so that they successively intersect the left-hand row of fingers. This short-circuits all of the resistor and brings the motor up to speed in the reverse direction.

MAGNETIC CONTACTOR CONTROL

A simple starter of this type is illustrated in Fig. 41. The controller consists of a slate panel, at the top of which are mounted a knife switch, with two fuses for overload protection, and four contactors underneath. A contactor is a switch which is held in the *open* position by gravity and closed by a magnet, Fig. 42. Contactor *1*, Fig. 41, is provided with a blowout coil, because of opening and closing the main motor circuit. Contactors *2*, *3* and *4* are used for short-circuiting the starting resistor sections, which are mounted in the rear of the panel. This arrangement is shown diagrammatically in Fig. 43. At the left is a scheme of main connections. At each point where the circuit is broken by two small parallel lines is a contactor. The numbers opposite these parallel lines are the same as shown in Fig. 41. The single loops represent the series coils for contactors *2* and *3*. An arrow is drawn between the parallel lines representing these switches and the loop representing the coil for each particular contactor. Underneath this scheme of main connections is shown a table called "Sequence of Switches." This table has four vertical rows in which circles are drawn. The first row represents the first starting position of the controller, and the last row the running position of the controller. Where a circle is shown opposite a switch number it indicates that that contactor is closed. This table is used as follows:

In the first vertical column, opposite *1*, is shown a circle which indicates that the contactor *1* is closed. This operation connects the shunt field of the motor from the point B to the negative side of the line. This arrangement of shunt field connections is the same as previously explained. Now refer to the schematic diagram and trace the main current from the positive side of the line through contactor *1* and the coil of *2*, to R_1 of the resistor, through this resistor to the A_1 terminal of the motor, through the motor armature and series field, to the negative side of the line. Referring to the table, in the second column contactor *2* is also closed, the path of the current being from the positive side of the line through *1* and *2* contactors, the coil of contactor *3*, to R_2 on the resistor, and from there it follows the same path as for the first column. The third column of the table shows that contactor *3* is closed. The current now passes to R_2, as previously described, through one section of the resistor to R_3, from here to A_1 on the motor armature, and through the armature and series fields to the negative line. The fourth column of the table shows that contactors *1* and *4* only are closed. The path of the current then is from the positive line through switch *1* to *B*, then through switch *4* to A_1, through the armature and series field to the negative line. This connects the motor directly to the line, without any external resistance, and is the full-speed position of the controller.

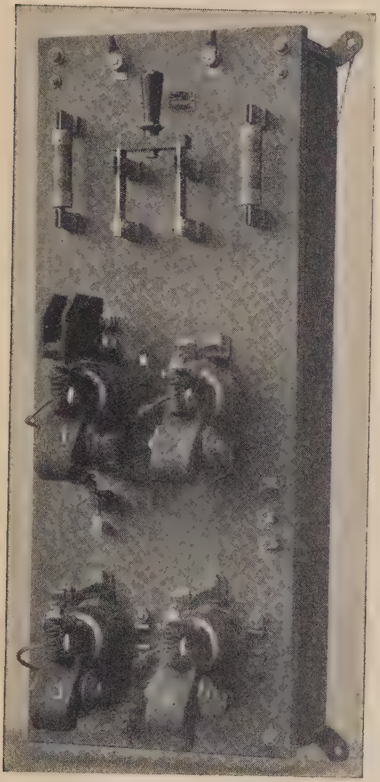
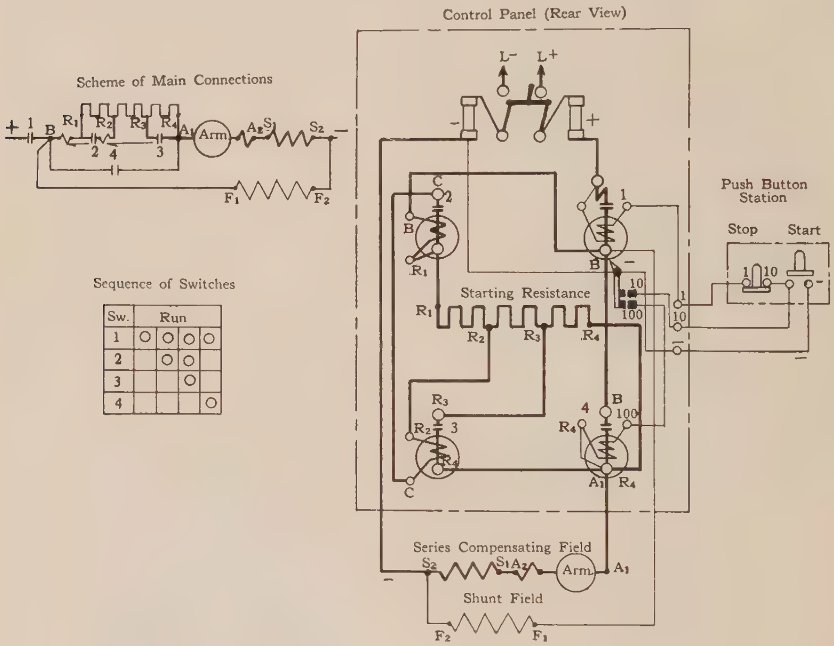


FIG. 41. Magnetic Contactor Control Panel

FIG. 42. Contactor Used on Control Panel of Fig. 30

Referring now to the main diagram, Fig. 43, the magnetic contactors are represented by a circle and the operating coils are shown inside of the circles. The moving contact is represented by the bottom of the two parallel lines. The upper parallel line is the stationary contact connected to the upper terminal of the switch. When the coil is energized sufficiently to attract the armature, the two parallel lines are brought together and current can flow between the top and bottom terminals of the switch. Underneath contactor *1* is a small switch, indicated by square dots, and a pivoted arm. When *1* is open, this auxiliary switch, known as an "interlock," is also open. The two contacts connected to the arm of this interlock are joined together electrically and to the hinge joint, so that they complete the circuit between the stationary contacts *10* and *100* and the pivot, when *1* closes. To the right of the diagram is a rectangle enclosing two push-buttons. The button marked *start* is held in the open position by a spring and the *stop* button is held in the closed position by a spring. If the *start* button is depressed for a moment, current flows from the positive line through the knife switch and fuse to the coil of switch *1*, through this coil to the terminal *1* of the *stop* button, to terminal *10* and through the *start* button, fuse, and knife switch, to the negative side of the line. This energizes the coil of contactor *1* and closes the main contact. This coil is now connected from terminal *1* through the *stop* button to terminal *10* on the interlock underneath this



Sw.	Run			
1	O	O	O	O
2		O	O	
3			O	
4				O

FIG. 43. Diagram of Connections of Controller Shown in Fig. 41

switch to the negative side of the line, which makes the circuit to the coil *1* independent of the *start* button, so that this button may now be released. The current now passes from the positive side of the line through the contact *1* and across to terminal B on *2*, through the coil of this contactor to R_1, through the starting resistor to R_4, thence to the bottom terminal of *4* to A_1 on the motor, through the armature and series fields of the motor to the negative side of the line. As the motor increases in speed the current through the coil of *2* decreases until this contactor closes. Contactors operates on what is known as the "lockout" principle, *i.e.*, it closes when its current is below a set value and above another much lower value. When *2* closes it short-circuits one section of the starting resistor from the terminal R_1 through the contact on *2* to the terminal C, through the coil of *3* to R_2 on the resistor. This again increases the current of the motor and prevents *3* from closing until the current has decreased to a fixed value. When *3* closes it short-circuits the section of the resistor between R_3 and R_4. This leaves the resistor section between R_2 and R_3 in series with the motor. The coil of contactor *4* is in shunt across the armature of the motor. The circuit is from A_1 through the coil to terminal *100* on the interlock underneath *1*, through this interlock to the hinge joint which is connected to the negative line. Since the A_2 terminal of the motor armature is connected to the negative side of the line, the voltage across this coil is equal to the counter e.m.f. of the motor. When the speed of the motor reaches the proper value, contactor *4* closes, connecting the A_1 terminal of the motor directly to $L+$ through the contact on *1*.

To stop the motor, push on the button marked *stop*, thus opening the circuit between terminals *1* and *10*, and disconnecting the operating coil of contactor *1* from $L-$. This opens contactor *1* and disconnects the motor from the positive line. The opening of switch *1* opens the contacts *10* and *100* on the interlock underneath, thus disconnecting the coil of contactor *4* from its motor armature circuit and leaving the equipment ready for operation again.

CHAPTER VI

HOW TO MAKE CONTROLLER DIAGRAMS

Definitions of types of diagrams—procedure in making automatic control diagrams—standard circuit designations and terminal markings—suggestions for making diagrams—points to observe in arranging circuits.

SKILL and experience are required to make a clear readable diagram. This is particularly true of the more complicated diagrams of automatic controllers. In making such diagrams, experience has pointed out a number of features which should be considered, most of which are based on existing practice that has developed with the art. A definite plan and method of procedure should be worked out for each diagram.

In order to classify the different types of diagrams The Electric Power Club adopted the following definitions.

1—Controller Wiring Diagram—A diagram showing the electrical connections between the parts comprising the controller, and indicating the external connections.

2—External Controller Wiring Diagram—A diagram showing the electrical connections between the controller terminals and outside points; such as connections from the line, to the motor, and to auxiliary devices.

3—Controller Construction Diagram—A diagram indicating the physical arrangement of parts, such as wiring, buses, resistor units, etc. Example—A diagram showing the arrangement of grids and terminals in a grid-type resistor.

4—Elementary Controller Diagram—A diagram using symbols and an elementary plan of connections to illustrate, in simple form, the motor circuits and the scheme of control.

5—Control Circuit Line Diagram—A diagram showing in simple form the path of each branch of the control circuit from line to line.

6—Control Sequence Table—A table indicating the connecting devices that are closed for each successive position of the controller.

Several of these diagrams are illustrated in order to make the definitions more easily understood. It is desirable to have a definite name for each kind of diagram, in order that engineers may better understand each other in discussing questions. In adopting these definitions The

Electric Power Club considered all of the names commonly used for these different diagrams and formulated names and definitions which seemed the most logical to describe particular diagrams.

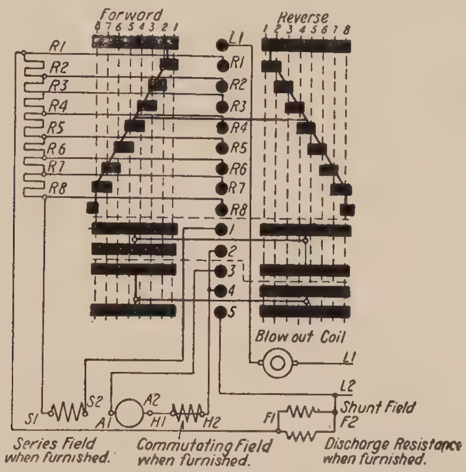


FIG. 44. Typical Diagram of Reversing Drum Controller with Magnetic Blowout

For shunt and compound direct-current motors

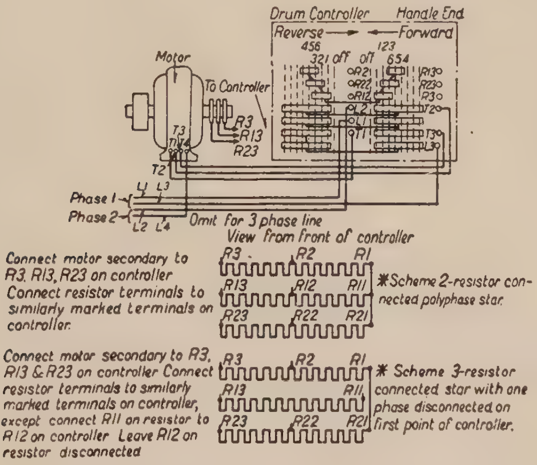

Drum Controller Handle End
Reverse
Forward
456
321 off
off 123
654
R21
R22
R12
R13
R23
R3
L2
L1
T1
T3
Motor
To Controller
R3
R13
R23
T3
T1
T4
T2
L1 L3
Phase 1
Phase 2
L2 L4
Omit for 3 phase line
View from front of controller
R3
R2
R1
R13
R12
R11
R23
R22
R21
Connect motor secondary to R3. R13, R23 on controller Connect resistor terminals to similarly marked terminals on controller.
✱Scheme 2-resistor connected polyphase star.
R3
R2
R1
R13
R11
R23
R22
R21
Connect motor secondary to R3. R13 & R23 on controller Connect resistor terminals to similarly marked terminals on controller, except connect R11 on resistor to R12 on controller Leave R12 on resistor disconnected
✱ Scheme 3-resistor connected star with one phase disconnected on first point of controller.

FIG. 45. Typical Diagram of Reversing Drum Controller

For two-phase or three-phase, wound-secondary induction motors

The diagrams for manual controllers, such as drum controllers and face plate control, are the simplest. Typical illustrations of these diagrams are shown in Figs. 44 and 45. Often the complete diagram can be made up without first making an elementary controller diagram.

Diagrams for automatic control using magnet contactors can best be made up by first working out the elementary diagrams in the following order, using the symbols shown in Fig. 46.

1—Make an elementary controller diagram (definition 4, Fig. 47).
2—Make a control sequence table (definition 6, Fig. 48).
3—Make the control circuit line diagram (definition 5, Fig. 49).
4—Make the complete controller wiring diagram (definition 1, Fig. 50).

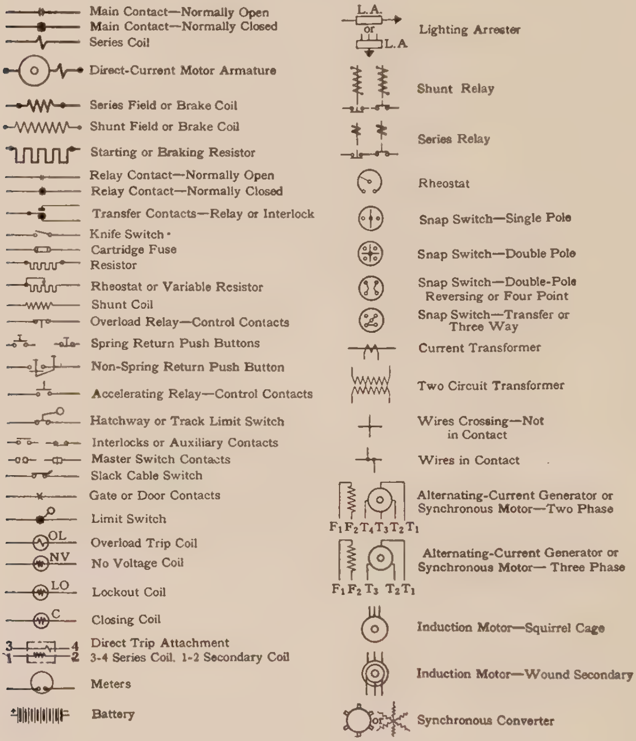

Main Contact—Normally Open
Main Contact—Normally Closed
Series Coil
Direct-Current Motor Armature
Series Field or Brake Coil
Shunt Field or Brake Coil
Starting or Braking Resistor
Relay Contact—Normally Open
Relay Contact—Normally Closed
Transfer Contacts—Relay or Interlock
Knife Switch
Cartridge Fuse
Resistor
Rheostat or Variable Resistor
Shunt Coil
Overload Relay—Control Contacts
Spring Return Push Buttons
Non-Spring Return Push Button
Accelerating Relay—Control Contacts
Hatchway or Track Limit Switch
Interlocks or Auxiliary Contacts
Master Switch Contacts
Slack Cable Switch
Gate or Door Contacts
Limit Switch
OL
Overload Trip Coil
NV
No Voltage Coil
LO
Lockout Coil
C
Closing Coil
3
4
1
2
Direct Trip Attachment
3-4 Series Coil. 1-2 Secondary Coil
Meters
Battery
L.A.
or
L.A
Lighting Arrester
Shunt Relay
Series Relay
Rheostat
Snap Switch—Single Pole
Snap Switch—Double Pole
Snap Switch—Double-Pole Reversing or Four Point
Snap Switch—Transfer or Three Way
Current Transformer
Two Circuit Transformer
Wires Crossing—Not in Contact
Wires in Contact
F₁ F₂ T₄ T₃ T₂ T₁
Alternating-Current Generator or Synchronous Motor—Two Phase
F₁ F₂ T₃ T₂ T₁
Alternating-Current Generator or Synchronous Motor— Three Phase
Induction Motor—Squirrel Cage
Induction Motor—Wound Secondary
or
Synchronous Converter

FIG. 46. Symbols Commonly Used in Controller Diagrams

If the controller is complicated, it may be desirable to make an external wiring diagram (definition 2). If the controller is for a large motor, where a heavy bus structure is necessary for carrying the current, it may be necessary to make a controller construction diagram.

STANDARD DESIGNATIONS

All contactors, relays, coils, interlocks, etc., should be marked. The following markings are recommended and some of them have been adopted as standard.

Contactors—1 and 3—Forward or up. 2 and 4—Reverse or down. 5 and 6—Line contactors (use No. 5 with reversing direct-current controller). 7 to 10—Other main switching purposes. 11 to 20—Direct-current armature series resistance contactors and contactors in wound rotor induction motor secondary circuits, used for starting and regulating. 21 to 30—Armature shunt and dynamic braking contactors. Back Contact—Number followed by *A*.

On direct-current double-pole contactors and alternating-current primary contactors each contact should have a different number as required by the standard marking. Accelerating contactors should be numbered in the order in which they close, i.e., No. 11 closes first, No. 12 second and so on.

Relays—Overload—OL. Low Voltage—LV. Brake Relay—BR. Field Relay—FR. Transfer Relay—TR. Accel. Relay—Symbol from Fig. 46, followed by the number of contactor by which it is operated. Direct Trip Attachment—DTA. Other relays and control contacts on motor-operated cam controllers 31 up.

Other Apparatus—Circuit Breaker—CB. Master Switch—MS. Limit Switch—Limit Switch (spell out). Interlock—Symbol from Fig. 46 followed by number of contactor or letter of relay by which it is operated. Knife Switch—Symbol from Fig. 46 followed by the number and by Sw.

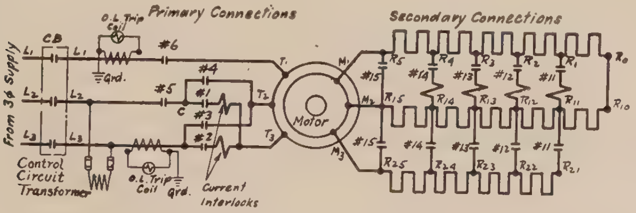


FIG. 47. Example of Elementary Controller Diagram

When more than one panel appears on the same diagram add a dash and the panel number after the regular marking of relays, contacts, interlocks, etc.

Instrument transformers should be marked "Current Transformer" or "Potential Transformer." Transformers supplying control circuits should be marked "Control Circuit Transformer."

Terminals—The following terminal markings have been adopted as standard by The Electric Power Club:

	Direct Current	Alternating Current
Line	L_1-L_2	$L_1-L_2-L_3$ etc.
Brush on Commutator	A_1-A_2	$A_1-A_2-A_3$ etc.
Stator		$T_1-T_2-T_3$ etc.
Series Field	S_1-S_2	
Brush on Slip Ring (Rotor)		$M_1-M_2-M_3$ etc.
Shunt Field	F_1-F_2	F_1-F_2
Commutating Field	C_1-C_2	
Braking Resistance	$B_1-B_2-B_3$	$B_1-B_2-B_3$ etc.
Armature Resistance	$R_1-R_2-R_3$	$R_1-R_2-R_3$ etc.
Shunt Field Resistance	$V_1-V_2-V_3$	$V_1-V_2-V_3$ etc.
Transformer, High Voltage		$H_1-H_2-H_3$ etc.
Transformer, Low Voltage		$X_1-X_2-X_3$ etc.
Two Phase Line		Phase 1 Mark L_1-L_3 Phase 2 Mark L_2-L_4
Two Phase Stator		Phase 1 Mark T_1-T_3 Phase 2 Mark T_2-T_4

The connection between the fused knife switch and fuse should not be marked. Terminals of meters should not be marked.

When two points with standard marking are connected to the same terminal (such as S_2 and R_4) give both markings at the point where the connection is made. Letters A-B-C-F-H-L-M-R-S-T-V-X should not be used for terminal markings other than given above.

Mark pilot motor terminals the same as for the main motor except use small letters a_1 — a_2 — f_1 — f_2 — s_1 — s_2.

When more than one motor or when motors and generators having the same marking are shown on one diagram the regular marking must be preceded by a letter indicating the machine to avoid confusion when making connections.

Examples—For Generator —GA_1—GA_2—etc. For Motor—MA_1—MA_2—etc. For Exciter—EA_1—EA_2—etc.

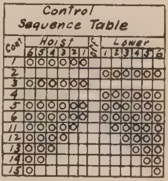
Resistor marking on diagrams must agree with marking on the resistance drawing.

Additional Terminal Markings—Shunt Brake Coil—b_1—b_2. Control Circuit —x—y (unless connected directly to terminals having different marking). Grounded Terminal—G.

Autotransformer terminals are marked 1, 2, 3, etc. To avoid errors in making connections the transformers should be marked "Transformer C," "Transformer D" and "Transformer E." On the controller, the terminals to which Transformer C is connected are usually marked 1C, 2C, etc., these terminals being connected to taps 1, 2, etc., on transformer

C. The terminals to which transformers D and E are connected are usually marked 1D, 2D, etc., and 1E, 2E, etc. For three-phase, terminals marked 1 are usually connected together, either permanently or while starting.

In addition to standard symbols and markings for apparatus and terminals, it is also desirable to mark the control lines so that they can easily be traced, especially on complete diagrams; otherwise it is sometimes very difficult to trace the connections and understand the operation of a complicated diagram. The most satisfactory and easily understood method of designation is to number the wires decimally, as shown schematically in Fig. 51 and in actual diagram in Fig. 50. The energy supply lines for the control are marked + and — for direct current, and x and y for alternating current. Where the supply line goes through a relay or limit switch before reaching the master controller, it is numbered 0. Where two or more of these are in series, they are considered as a unit, and no markings are placed between them. When they are in parallel, or in series with taps taken off between them, these are numbered 0, 00, 100, 101, etc.



Control Sequence Table

Cont	Hoist						Off	Lower					
	6	5	4	3	2	1		1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3	○	○	○	○	○	○							
4								○	○	○	○	○	○
5	○	○	○	○	○	○		○	○	○	○	○	○
6	○	○	○	○	○	○		○	○	○	○	○	○
11	○	○	○	○	○				○	○	○	○	○
12	○	○	○	○						○	○	○	○
13	○	○	○								○	○	○
14	○	○										○	○
15	○												○

FIG. 48. Example of Control Sequence Table

The fingers of the master switch, or the contacts of control push buttons, etc., and the lines leading therefrom are numbered 1, 2, 3, etc., odd numbers giving forward and even numbers negative rotation on a reversing controller. Each line is given the same number at both ends and, if long, at convenient intermediate points to make it easier to trace. When a circuit goes through a coil, interlock or other equipment, the number is changed, being multiplied by ten at the first break and increased by one at each additional break, as shown in Fig. 51, until it reaches the other terminal—or y. Where a line branches, the branches are numbered, when possible, in the order of normal operation. Where a line taps onto one previously numbered it takes the number first assigned, as shown in Fig. 8. By this system, any line with a number starting with 2, for example 20, 21 or 24, originates on master controller finger 2. This is a great convenience in studying the diagram.

GENERAL SUGGESTIONS

Simplify the diagrams as much as possible; the lines should be at least one-eighth inch apart. Main line connections should be shown by heavy lines and control circuit connections by lighter lines. In no case should the lines be too fine to blueprint clearly. Double crossings of lines should be avoided and single crossings used as little as possible. Make the connections with few bends or offsets and where possible in straight lines. Make all lines in the diagram, except very short connections, either horizontal or vertical. Do not show connections running diagonally across the diagram. Shunt field and shunt braking connections should be shown by light lines; armature and dynamic braking connections by heavy lines. These connections are mentioned merely as illustrations; the principles can be applied to all of the other connections.

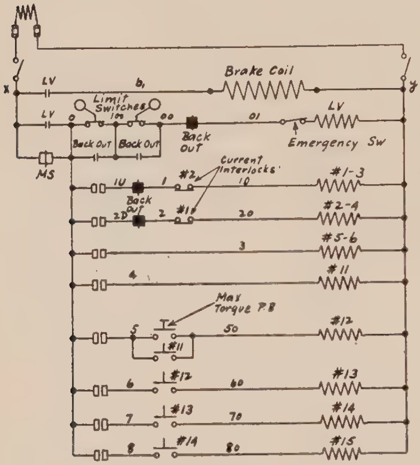


FIG. 49. Example of Control Circuit Line Diagram

On controllers for large motors, all heavy line connections are made by copper strap. The controller should be arranged so that these connections are as short and straight and with as few cross-overs as possible. These heavy connections add materially to the cost of the controller and it is desirable to spend ample time in arranging the controller so as to reduce the cost of these connections.

Controller diagrams usually show the rear view of the panel, as connections are usually made on this side of the panel and the wireman who uses the diagram faces the rear of the panel. External wiring diagrams are made facing the front of the panel if the external connections are located on the front of the panel; otherwise this diagram should be made as though facing the rear of the panel.

Each separate piece of apparatus should be enclosed in a rectangle made up of a broken line, as shown in Fig. 50. This indicates what part of the diagram applies to each piece of apparatus. It also shows where the wires pass from one piece of apparatus to another.

Small resistors mounted directly on the panel should be shown in their relative positions. This is particularly true of small resistor tubes connected in series with magnet coils.

The parts of a motor or generator, such as the armature, field coils, and brake coils, should be shown grouped together. Where motors, generators, and exciters are coupled together they should be so indicated on the diagram.

When a control circuit switch is divided from the main circuit knife switch it should be connected outside of the main knife switch, so that the control connections can be tested without starting the motor.

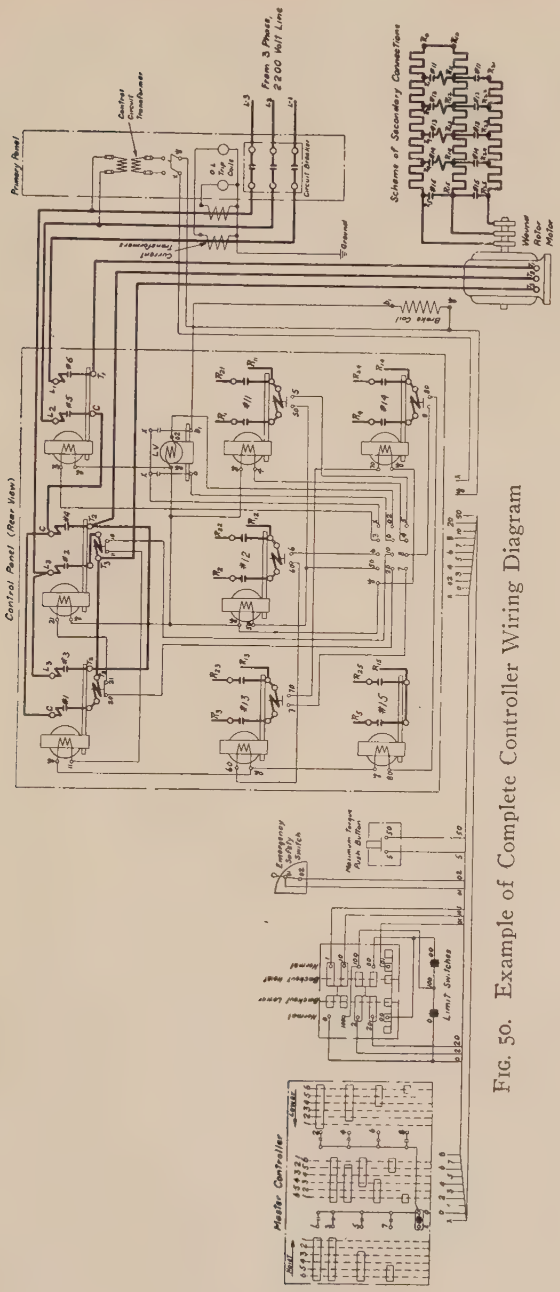


Fig. 50. Example of Complete Controller Wiring Diagram

It is customary to group the control circuit terminals close together, usually near the bottom of the panel. This is very convenient in making the connections to the master switches and other auxiliary apparatus. In the smaller controllers the main line connections are often grouped together, either at the top or bottom of the panel. For the larger controllers the lugs for external connections are located on different parts of the panel in order to reduce the number of joints in the circuit.

When a knife switch and fuse are used, connect the switch to the line in such a way that the fuse will be dead when the switch is open. This is done by connecting the fuse to the hinge terminals of the switch and the line to the other terminals. Single-throw switches should open in the direction of gravity, to prevent the switch from accidentally closing. Do not place a knife switch above the main contactor, as the arc from the contactor may burn the operator's hand.

The connection of two or more controller coils in parallel causes sluggish opening of the contactors, due to the discharge between the coils. This is particularly true with large contactors or where coils of different sizes are in parallel. It is advisable to separate coil circuits in all cases.

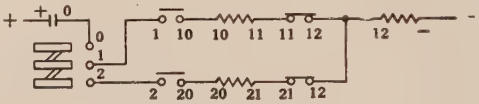


Fig. 51. Portion of Elementary Diagram, Showing How Intermediate Points of Branch Control Circuits are Marked

If a resistor is connected in parallel with a coil it gives slow opening of the contactor; the lower the resistance the slower the action. If a resistor is connected in series with a coil and the coil design is so modified that the resultant flux is the same as before, the speed of closing is increased; the greater the resistance the greater the effect.

If a condenser is connected in parallel with a contactor coil, it may cause the contactor to open more quickly. If there is considerable residual magnetism, the condenser may increase the time of opening, rather than decrease it. A condenser should be used with considerable care where the time of opening is an important factor.

The above two paragraphs apply to direct-current control, as it is not good practice to use resistors or condensers in connection with alternating-current control equipment. The use of a resistor or condenser is ordinarily for the purpose of reducing the arcing on a control contact in series with direct-current coils. They may, however, be used to advantage in some cases in timing the operation in order to obtain a desired sequence.

Where one side of a circuit is grounded, the master switch should be connected to the opposite side of the line. It is desirable to connect the master switch to the same side of the line as the motor armature of a direct-current motor, in order that the elementary diagram and the control line diagram may show both the armature and the master switch on the left-hand side. When two or more panels are controlled from one master switch, special care must be taken to avoid "sneak" circuits. That is, after circuits have been established and checked to see that they will produce the desired operation, an extra check should be made to ensure that no additional unintended operation is possible. Cam-type master switches have each contactor separately insulated. Where practicable use a separate cam contactor for each control panel. Where a drum-type master switch is used it may be necessary to provide separately insulated sections of the drum for each panel.

It is desirable to provide only one control knife switch and fuse for the entire equipment. Where the control circuit to each panel is not insulated through the master switch, all overload relays and the low-voltage protective relay should have their contacts connected in series.

Where a try-out switch is provided on the control panel it should be electrically interlocked with the master switch in such a way that when the try-out switch is used the master switch will be inoperative.

The illustrations of diagrams shown in this article are intended to represent general methods of making diagrams. Other symbols may be found better adapted for various designs of apparatus.

SUMMARY OF CHAPTER VI

Make the diagrams for automatic controllers in the following order:

(1) Elementary controller diagram (showing in simple form the control scheme and motor circuits);

(2) Control sequence table (showing the order in which each connecting device closes);

(3) Control circuit line diagram (showing in simple form the path of each branch of the control circuit from line to line);

(4) Controller wiring diagram (showing wiring between the parts of the controller and also the external connections);

(5) (If the controller is unusually complicated) external wiring diagram (showing connections between the line, controller, motor, and auxiliary devices);

(6) (If motor is large) controller construction diagram (showing physical arrangement of buses, resistors, etc.).

Use the standard markings for the various motor and control parts and terminals, as far as possible.

When more than one motor, transformer, etc., are used, differentiate them by additional markings to the standard markings.

Mark control supply lines for direct current + and —, for alternating current x and y.

Simplify diagrams as much as possible.

Space lines at least one-eighth inch apart.

Show main line connections by heavy lines.

Show control circuits by lighter lines.

Make copper strap connections short and as straight as possible.

Show rear view of panel if wireman faces rear when wiring.

Separate pieces of apparatus should be so indicated by enclosure in broken line rectangles.

Show resistors mounted in their relative positions.

Group the parts of a rotating unit (for example, the armature, shunt field, and brake coil of a motor).

Connect control circuit switch outside of main line switch so that control can be tested without starting the motor.

Group control terminals together.

Connect the hinge jaws of knife switches to fuses, and the break jaws to the line, so that when the switch is open the fuse is dead.

Mount the break jaw above the hinge jaw so that the switch will not close if the blade accidentally drops.

Do not mount knife switches above the main contactors as the arc from the latter may burn the operator's hand.

Carefully consider the effect before placing a coil, resistor, or condenser, in parallel with coils.

In applying master switches take care to avoid sneak circuits causing unintended operation.

CHAPTER VII

ACCELERATION OF MOTORS, COUNTER E.M.F. AND SERIES RELAY METHODS

Five methods of automatic acceleration of motors—principle of counter e.m.f. method—diagram explained—advantages and limitations—a modification that simplifies—principle of series relay method—diagram explained—advantages and limitations.

Methods of Accelerating Motors

In starting a motor from rest and bringing it up to full speed, resistance is inserted in the armature circuit of a direct-current motor, or the rotor circuit of an induction motor, to limit the current. This resistance may be short-circuited gradually by a manually-operated controller, as explained in Chapter V, or the resistance may be short-circuited in steps automatically as the speed of the motor increases. There are several methods of short-circuiting this resistance automatically, as follows:

1. Counter e.m.f. method.
2. Series relay method.
3. Series lock-out contactor method.
4. Time element method.
5. Current limit method.

Sometimes a combination of several of these methods is used in one controller. This chapter explains the fundamental principles involved in these different methods of automatic acceleration.

Counter e.m.f. Method

This method has been developed for use with direct-current motors only, and is commonly used with shunt, or standard compound-wound motors. When a motor is started from rest and accelerated to full speed, the voltage across the rotor terminals increases as the speed of the motor increases. If the coil of a magnetic contactor is connected across the motor brushes, the current in this coil will increase as the speed of the motor increases. By adjusting the air-gap in the magnet, the contactor may be made to close at a fixed voltage across the motor brushes. The closing of the contactor can be made to short-circuit a section of the armature resistance. By adjusting several contactors to close at different armature voltages, the series steps of the starting resistance can be short-circuited and the motor brought up to full speed.

A simple diagram with one step of armature resistance, and one magnetic contactor for short-circuiting this resistance, is shown in Fig. 55. Several steps of starting resistance could, of course, be used with a contactor for short-circuiting each section.

The closing of switch *1*, which is operated by a push-button, connects the motor to the line in series with the starting resistor. One end of the operating coil of this switch is connected to the negative side of the line, and the other end is connected through the push-button to the positive side of the line. The coil of switch *2* is connected across the brushes of the motor armature, and will close the switch when the counter e.m.f. of the motor reaches a predetermined value. The closing of this short-circuits the starting resistor R_1R_2, and places the motor directly across the line in the regular operating position.

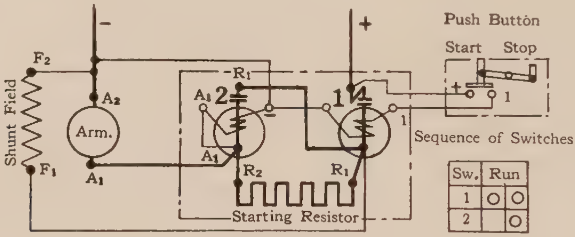


FIG. 52. Diagram of Connections

Using the counter e.m.f. method of accelerating motors

With the elementary arrangement shown, if switch *1* is opened by pushing the stop button, switch *2* will not open immediately, as it will be held in by the counter e.m.f. of the motor. With most commercial switches a counter e.m.f. of 25 per cent of the full-speed value will hold the contactor closed. Under this condition, when the motor speed has been reduced to one-fourth full speed, and with contactor *2* still in the closed position, the start button can be pushed, thus closing line switch *1*, with the result that the motor will be connected directly across the line, without any starting resistance, and may cause a severe jar to the motor and machinery which the motor drives. In order to avoid such a possibility, in commercial controllers an interlock is usually provided on switch *1*, which opens the current of the coil on switch *2* whenever switch *1* is opened.

The advantages of this method of acceleration consist in its simplicity, since the switch does not need an auxiliary relay or other accelerating devices.

Limitations arise where there is a considerable variation in the line voltage. An increase in line voltage will cause the contactor to close sooner than it should, and a drop in line voltage sometimes prevents the contactor from closing. These, however, are extreme cases. With a reasonable system of power distribution, especially if the power circuit is used for lights, the variation of voltage will be small, and no trouble should be experienced. Another disadvantage may be caused by a change of adjustment, due to a change in temperature in the operating coil of the contactor. With a properly designed contactor, however, changes in the coil temperature will not cause trouble.

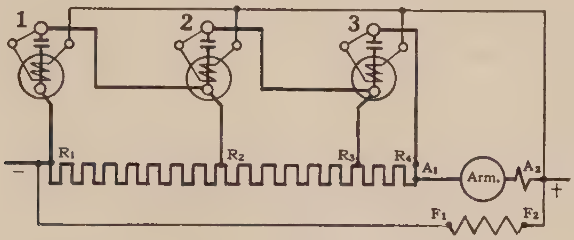


FIG. 53. Part of Diagram of Connections

Showing three contactors for regulating acceleration by the counter e.m.f. method

Where several contactors are to be installed it is often necessary to furnish different coils, in order that adjustments can be made over the wide range of voltage necessary for the operation during acceleration. Interlocks are used for dropping out all but the last switch, in order to protect the low-voltage coils from overheating.

A modification of the connection shown in Fig. 52 is often used, in order to keep all of the coils alike, and eliminate the interlock on the last switch. This arrangement is shown in Fig. 53. The operating coils of all contactors have one side connected to the motor brush farthest away from the starting resistor. The other sides of the operating coils are connected to the taps on the starting resistor, the coil on switch *1* being connected to R_2 on the resistor. The voltage on this coil is equal to the line voltage, less the drop in voltage through the first section of the resistor. As the speed of the motor increases, the counter e.m.f.

causes a decrease in the armature current. This reduces the drop through the first section of the starting resistance. The voltage on the operating coil of switch *1* is gradually increased, until this switch closes. Switch *2* has its operating coil connected to R_3 on the starting resistor. The voltage on this coil is increased by the closure of switch *1*. The increase in current, however, at this instant, causes a considerable drop in the second section of the starting resistance. As this current gradually decreases with the increased speed of the motor, switch *2* closes. The operating coil of switch *3* is connected across the motor armature, the switch closing when the counter e.m.f. of the motor is nearly equal to the line voltage.

Acceleration by Series Relay Method

There are a number of different schemes for using a series relay to control the acceleration of a motor. The principle involved in all of these schemes is a relay having a series winding which holds the relay contacts in the open position when the current exceeds a predetermined value. When the current is reduced sufficiently, the relay armature completes the circuit to the shunt coil of a magnetic contactor. This method of acceleration can be used for either alternating or direct-current motors. The arrangement most common in industrial applications consists of a series relay for each magnetic contactor. The relay contacts are held open mechanically until the electric circuit is closed with the maximum resistance in series. The relay armature is then released mechanically although not allowed to drop until the current is reduced to the value for which the relay is set. The dropping of the armature completes the circuit for the operating coil of a magnetic contactor, which short-circuits a section of the starting resistance.

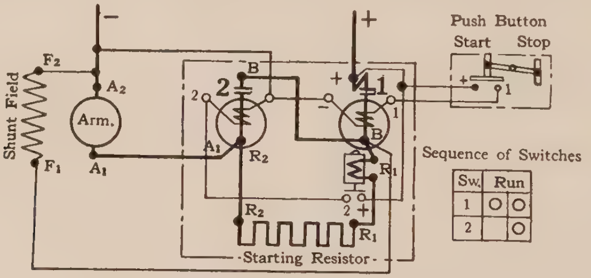


FIG. 54. Simplified Diagram of Connections
Using a series relay to regulate acceleration of the motor

A simple form of this type of control is shown in Fig. 54. Switch *1* is controlled by a push-button in the same way as in Fig. 52. This contactor is provided with a series relay mounted directly beneath the switch, whose contacts are connected to the positive line and through the operating coil of switch *2* to the negative line. When the relay armature is released, these contacts are connected together, thus causing switch *2* to close. When switch *1* is open, the contacts of the relay are held in the open position by a spring. When switch *1* closes, it releases this spring by mechanical means, so that the contacts may close. The current, however, in the series coil holds the armature in the upper or open position until the current has been reduced to a predetermined value. The armature then drops and its contacts are closed. This will not occur until after the motor has approached full speed, so that when switch *2* closes and short-circuits the starting resistor the increase in current will be limited. Several sections of armature resistance may be used with switches for short-circuiting each section, each switch being controlled by a series relay mounted on the preceding switch in the manner described.

The advantages of this method of acceleration are:

1. The short-circuiting of the starting resistor depends directly upon the motor current.
2. This method is not affected by variation in line voltage, providing there is sufficient voltage to close the magnetic contactors.
3. The adjustments for closing are not affected by the heating of the coil.
4. This method limits the load under which the motor will start. If the load is too great to allow the motor to accelerate sufficiently to reduce the current to the predetermined value the relay will not drop and close its contacts, and therefore the starting resistance will not be short-circuited.

The limitations of this method are:

1. This method may result in too rapid an acceleration of the motor under light loads.
2. Additional apparatus is required, viz., a relay for each resistance contactor.
3. The motor may fail to start under overload. This was given as an advantage, but in some cases it may be a disadvantage, depending upon the application.

SUMMARY OF CHAPTER VII

Resistance used in starting a motor and bringing it up to full speed may be short-circuited automatically by one or more of the following methods: counter e.m.f., series relay, series lockout contactor, time element, or current limit.

Counter E.M.F. Method: The counter e.m.f. method utilizes the gradually increasing counter e.m.f. across the motor armature to operate contactors adjusted to close at different voltages and short-circuit in succession the steps of the starting resistor. This method is a simple one, but fluctuations of line voltage or coil temperature may affect operation.

Series Relay Method: Each short-circuiting contactor on closing releases mechanically a relay which is held open by a series coil until the current drops to a predetermined value, when it closes the operating circuit of the next contactor.

In comparison with the counter e.m.f. method, the series relay is not affected by coil temperature or small fluctuations in line voltage, but separate relays are required for each accelerating contactor. As the relay depends upon the motor current values, the motor may not start on overloads or may accelerate too rapidly on light loads.

CHAPTER VIII

ACCELERATION OF MOTORS, SERIES LOCKOUT CONTACTOR METHOD

Lockout contactors, operation and types—single coil, clapper type (saturated iron circuit)—single coil, solenoid type (saturated iron circuit)—single coil, clapper type (iron circuit not saturated)—double coil, solenoid type (saturated iron circuit)—series lockout, shunt closing, coil, clapper type (iron circuit not saturated).

SERIES LOCKOUT CONTACTORS

THE series lockout contactor, when used for accelerating a motor, depends on the value of the armature current in the same way as the series relay method of acceleration. The contactor is designed so that it is held in the open position when the current through the operating coil or coils is in excess of a fixed value. When the current decreases to the value for which the contactor is set, it closes. There are two general types of these contactors, one using a single coil and the other a double coil. Some contactors depend for their operation on the saturation of the magnetic circuit, others are designed for circuits not saturated.

The motor armature current may pass through the operating coil or the operating coil may be connected across a shunt in this circuit. A very convenient form of shunt is the starting resistor.

SINGLE COIL CONTACTORS WITH SATURATED IRON CIRCUIT

This type of lockout contactor is the one most easily understood. The following are several examples of this design.

Referring to Fig. 55 the path of magnetic flux is as follows:

Starting from the upper end of the core in coil *C* across the gap G_1, along the armature *A* to the pivot *P*, where the flux divides one portion flowing down the strip *L* across the gap to the projection *E*. Another portion flows down the iron shunt *S* to the projection *E*. The total flux then flows along *E* to the magnetic core of the coil.

When the current is switched through the coil *C*, and this current is higher than the closing value for which the device is adjusted, the attraction across the lower gap G_2 is sufficient to hold the contactor open against the attraction across the upper gap G_1. When the current falls, due to the acceleration of the motor, the magnetic flux in all parts of the magnetic circuit will decrease. Due to the higher magnetic reluctance of the magnetic circuit through strip *L* and air gap G_2, the flux will decrease in this circuit faster than in the shunt *S*. The magnetic attraction across the lower gap G_2, will fall at a greater rate than the decrease in the attraction at the upper gap G_1, and, finally, when the current reaches the adjusted closing value, the attraction at the lower gap G_2 can no longer hold the moving element and the contactor will close.

To make sure that the contactor will not close when the first onrush of current is within the range of the value at which the device is adjusted to close, the iron shunt *S* is encircled with a low resistance copper band *D*. When the current is first switched on, a heavy momentary current is induced in this copper band and this opposes the increase of the flux in the shunt *S*. This action causes a large portion of the flux to be forced across the gap *G*, while the current is rising, thereby increasing the attraction at this point and causing the contactor to lock out.

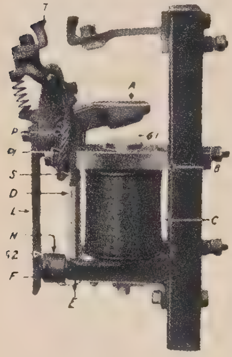


FIG. 55. Lock-out Contactor of Single Coil Clapper type

Fig. 56 shows the adjusting feature. This portion of the contactor is referred to in Fig. 55 as parts *E* and *N*. The part marked *E* is steel and constitutes part of the magnetic circuit. *N* is the knurled adjusting iron nut (magnetic) and is supported on the brass threaded screw *A* (non-magnetic). After proper adjustment has been made the screw *A* is securely held in place by means of a riveted pin. *D* is a click spring for holding the adjusting nut *N* in place but allows it to be turned. Since *A* is held stationary and *N* can be turned the air gap (G_2, Fig. 55) can be increased by screwing the knurled nut *N* back on the screw *A*. After the adjusting nut *N* has been set, the screw *C* should be tightened, to prevent it from turning.

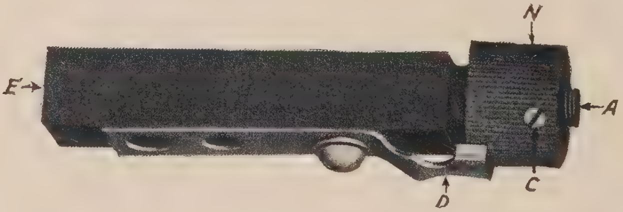


FIG. 56. Adjustment Feature of a Series Contactor

A lockout contactor of the coil and plunger type is illustrated in Fig. 57. The operation of this contactor can be understood by referring to Figs. 58 and 59. The flux passing through the air gap *U* tends to lift the plunger *P* which closes the contacts. This upward movement of plunger *P* is retarded by the magnetic flux in the air gap *D*. Part of the flux passing through *P* enters the narrow portion of the plunger and a part passes through the air gap *D*. The iron in the lower portion of plunger *P* becomes saturated at high current values, forcing a part of the flux through the air gap *D*. As the current through the coil *C* decreases, the total magnetic flux is less and the larger part of this flux passes through the narrow portion of the plunger *P* and less through the air gap *D*. When the current in the coil drops to the proper value, the flux through the air gap *D* is no longer able to prevent the upward movement of the plunger, which in turn closes the contacts.

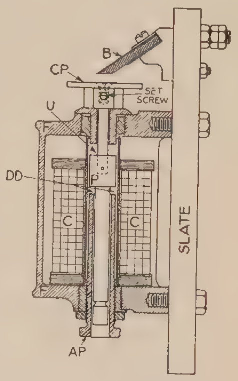


Fig. 57. Lockout Contactor of Single Coil, Solenoid Type

The contactor shown in Fig. 57 has its air gap *D* located at the end of the sleeve near the top of the operating coil. This air gap can be adjusted up or down by means of the threaded hollow plug *AP*. The greater the air gap, the higher the current value at which the contacts are closed.

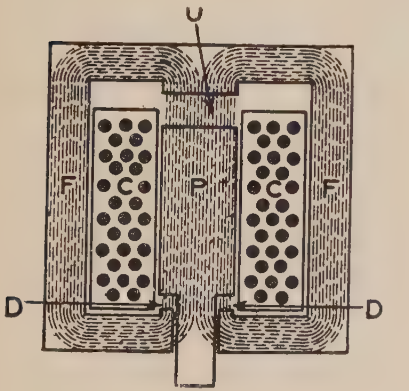


Fig. 58. Section of Lockout Contactor Magnet, Solenoid Type, Showing Distribution of Flux on Overload

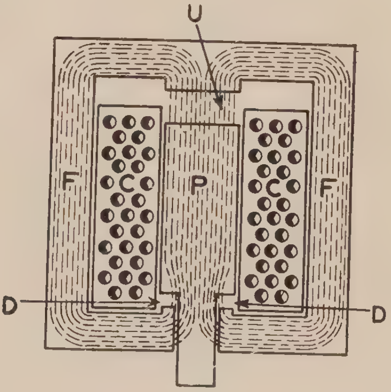


Fig. 59. Section of Lockout Contactor Magnet, Solenoid Type, Showing Distribution of Flux at time of Closing

A clapper type of lockout contactor is shown in Fig. 60. The flux or magnetism in the iron is caused by current flowing through the operating coil. This flux passes through the air-gap to the armature of the contactor. Part of this flux passes from the armature through the armature bracket to the magnet yoke, and thence to the magnet core. Another part of the flux passes from the armature through the tail piece to the magnet yoke. The flux through the tail piece exerts a pull which prevents the contactor from closing. The magnetic path through the armature bracket has a small cross-section, so that when the current flowing through the operating coil exceeds a certain value the bracket becomes saturated and the balance of the flux passes through the tail piece, holding the contactor open. As the current decreases, the flux in the saturated armature bracket remains constant, but the flux through the tail piece decreases until it is not sufficient to hold the contactor open. The switch can be adjusted to close at a predetermined current value by changing the hold-out air-gap between the tail piece and the magnet yoke. This air-gap is adjusted by means of a calibrating screw. The greater the air-gap at this point, the higher the current value at which the switch will close. When the circuit is first completed through the operating coil there is danger of the switch closing before the flux in the tail piece is sufficient to lock it open. This tendency is overcome by placing a heavy copper damping coil around a portion of the armature bracket. When the operating coil is energized, this coil forces the flux to build up in the tail piece in advance of the armature bracket.

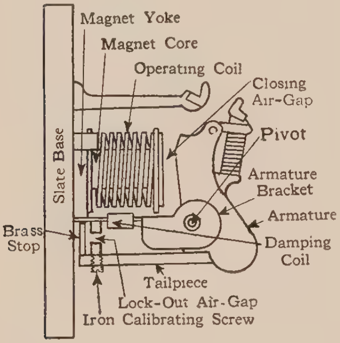


FIG. 60. Diagram of Series Lock-out Magnetic Contactor

SINGLE COIL CONTACTORS WITHOUT SATURATED IRON CIRCUIT

Contactors have been designed similar to the above except that the operation does not depend upon a portion of the magnetic circuit being saturated. Fig. 61 illustrates a contactor of this kind in which the adjustment depends on the force exerted by a spring.

The lower end of the armature *A* is situated between the polar surfaces *D* and *F*, of which *D* has the shorter air gap as determined by the brass pin *J* which is fastened to *D* and holds the armature at a fixed distance.

The spring pressure between the armature *A* and *B* is adjusted by the calibrating screw *E*, this screw being held in position as set by a spring which falls into the grooves of the knurled head of the screw. The screw *E* is turned clockwise to increase the spring pressure and thereby obtain a high current limit setting, or closing point. The screw *E* is turned counter-clockwise for a lower current limit setting.

The actuating coil *C* is connected in series with the armature of the controlled motor and when current higher than that for which the device is adjusted is switched on, the armature *B* closes against its pole face and exerts through the compressed spring a closing pressure against the armature *A*. This spring pressure against the armature *A* cannot overcome the opposing magnetic attraction across the pole piece *D* until the motor accelerates and the current falls in value to the point, as determined by the spring setting, where *D* releases. The armature *A* is then drawn against the pole *F* by the compressed spring and the pull of the pole and is held there by magnetic attraction. This action closes the contacts *T* and short-circuits that part of the starting resistor which is connected between them.

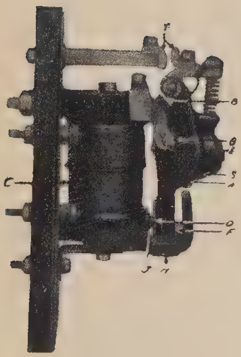


FIG. 61

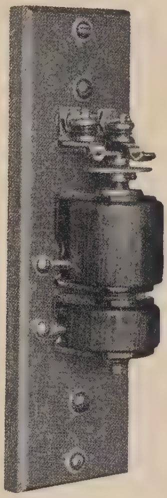


FIG. 62

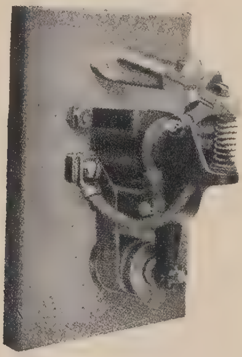


FIG. 63

FIG. 61. Series Lockout Contactor, Clapper Type with Double Armature
FIG. 62. Lockout Contactor with Double Series Coil Solenoid Type
FIG. 63. Lockout Contactor with Double Series Coil Clapper Type

The current limit setting is regulated by the calibrating screw *E* and is set for values of current below that at which the armatures *A* and *B* would close simultaneously.

DOUBLE COIL CONTACTORS WITH SATURATED IRON CIRCUIT

Contactors of this type are illustrated in Figs. 62 and 63. The two coils shown are series wound. The upper coil is used for closing the contactor and the lower coil for locking the contactor open. The upper or closing circuit has a restricted iron path so that the closing force is approximately constant over a considerable range of current. The circuit for the lower coil is not saturated and therefore the holding out force varies directly with the current. Both coils are energized at the same time. The first rush of current causes the lower coil to predominate and hold the contactor open until the current decreases to the value for which the contactor is set. At this current value the upper coil overcomes the force exerted by the lower coil and closes the contactor. The current setting at which the contactor closes can be adjusted by changing the air-gap at the pole face of the lower coil.

The contactor shown in Fig. 103 has an auxiliary magnetic path which comes into the magnetic circuit during the closing of the contactor and increases the magnetic pull when the contactor seals.

Double Coil Contactor without Saturated Iron Circuit Using a Series Lockout Coil and a Shunt Closing Coil

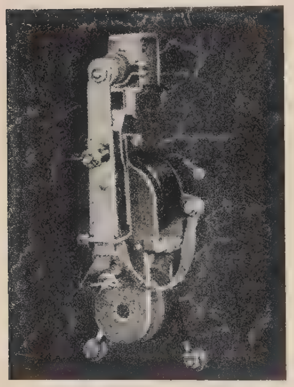


Fig. 64. Double Coil Contactor, without Saturated Iron Circuit, Using a Series Lockout Coil and a Shunt Closing Coil

This contactor is similar to the two coil contactors just described, with the exception that the closing coil is shunt wound and does not use a saturated circuit. The object of saturating a circuit of the closing coil is to give a uniform pull during the lockout period. By using a shunt coil this result is obtained without the saturated circuit. The contactor is illustrated in Fig. 64. The air gap in the lockout coil circuit is adjustable to provide the necessary calibration.

This particular design of contactor is provided with copper to copper current carrying contacts and copper to carbon arcing contacts. Contactors of the lockout type are usually connected to the starting resistance and do not require a magnetic blowout.

SUMMARY OF CHAPTER VIII

Series Lockout Contactors: Lockout contactors are held open when the current through the operating coil exceeds a predetermined value, closing when the current falls below this value. They may be of the clapper (magnet and armature) or solenoid (coil and plunger) type, employ one or two series coils, or one series and one shunt coil, and depend upon saturation of the closing coil magnetic circuit to obtain a uniform pull during the lockout period or procure this by other means.

Single series coil, clapper type, saturated iron circuit: At the starting current peak the flux, due to a larger closing air gap and a damping coil in the closing coil magnetic circuit, builds up faster in a lockout circuit and holds the contactor open. Owing to higher reluctance the lockout circuit loses its magnetism faster as the motor current subsides, until the closing circuit is able to close the contactor. Adjustment is made by varying the lockout air gap.

Single coil, solenoid type, saturated iron circuit: Owing to saturation of the lower portion of the plunger at starting, part of the flux traverses the lower air gap and holds the plunger down until the current falls, when the lower air gap flux becomes ineffective and the flux across the upper air gap raises the plunger and closes the contactor. A threaded sleeve in the magnetic circuit is turned to vary the lower air gap.

Single series coil, clapper type, iron circuit not saturated: At starting one armature closes, exerting pressure through a spring upon another armature which is held open by attraction of the lower end until the flux decreases, when the pull of the spring is able to close the contactor. Different settings are obtained by adjusting the spring.

Double series coil, solenoid type, saturated iron circuit: At the first rush of current the lower coil holds the contactor armature open against the pull of the upper, until the starting peak subsides, when the lower coil becomes ineffective and the upper coil closes the contactor. The magnetic path of the upper being restricted (saturated), the closing force is constant over a considerable range of current. The lower circuit not being saturated, the holding out force varies directly with the current. Adjustment is by varying the lower air gap. An auxiliary magnetic circuit may be added which becomes energized during the closing period and seals the contactor.

Double coil (series lockout, shunt closing), clapper type, iron circuit not saturated: A series coil is used to hold the contactor open during the starting peak, a shunt coil to close the contactor after the starting current and the magnetism of the series coil subsides.

CHAPTER IX

ACCELERATION OF MOTORS, TIME ELEMENT AND CURRENT LIMIT METHODS

Time element device for the acceleration of motors—dashpot type—pilot motor type—current limit method of motor acceleration—principle and description of operation—operation by springs versus by gravity—action of relay analyzed—calibration—use of relay to obtain deceleration—foregoing methods compared.

Time Element Method

Control apparatus using this method of acceleration may have the contactors or switches for short-circuiting the starting resistance controlled by a dashpot or other timing device.

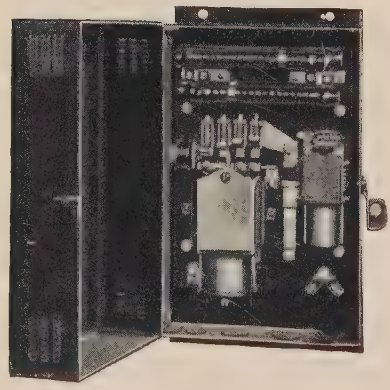


Fig. 65

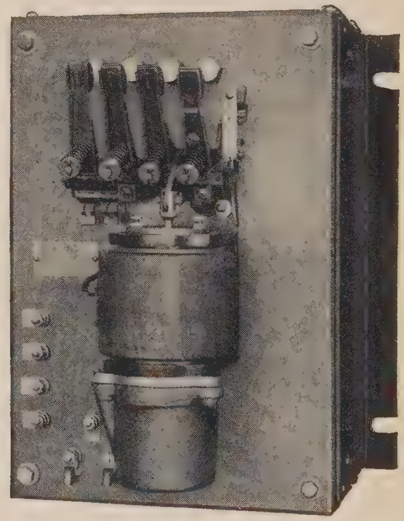


Fig. 66

Fig. 65. This d-c. Automatic Starter consists of a completely enclosed solenoid below which is mounted an air dashpot of the vacuum type which governs the time of acceleration. Above the solenoid are a number of resiliently mounted contacts which are successively engaged by a contact bar as the solenoid core is drawn upward. Each of these contact fingers controls a magnetic switch which in turn controls one step of resistance. The time of acceleration can be varied over a wide range by adjusting the air inlet valve at the bottom of the dashpot

Fig. 66. D-c. Automatic Motor Starter, Time Limit Acceleration Type

Each contactor may be provided with an independent dashpot or a small master switch can be used controlled by a dashpot. Controllers of the latter type are shown in Figs. 65 and 66.

Such a master switch completes the circuit to each contactor in turn with a time interval between so that the resistance is cut out in steps. A type of controller popular a number of years ago and still used to a considerable extent consists of a face plate shown in Fig. 67. The arm is moved by a magnet retarded by a dashpot.

A very successful type consists of a controller driven by a pilot motor through worm gearing. In the smaller sizes, the controller may be of the drum type. In the larger sizes, cam actuated contactors are used. The time of acceleration is adjusted by changing the speed of the pilot motor. The segments of the drum controller or the cam contactors short-circuit sections of the starting resistor. A complete controller of the drum type is shown in Fig. 69 and the cam type in Fig. 68.

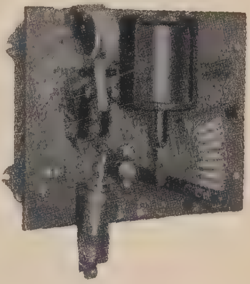


FIG. 67. D-c. Automatic Motor Starter, Time Limit Type

The advantages of a time element acceleration are:

(1) The device is usually quite simple in construction.

(2) Acceleration is smooth under all conditions of load.

(3) The motor will start under any load within the setting of the circuit-breaker. The device continues to short-circuit the resistor until the motor develops the necessary torque for starting the load. Where the load may be very heavy this type is superior to the current limit type as with the latter the motor may fail to start and as the circuit-breaker is often set for a higher value than the initial starting current, this circuit-breaker fails to open and the motor remains across the line with the armature and starting resistor in circuit, either of which may be injured if left in the circuit for any length of time under these conditions.

The limitations of this form of control are:

(1) Dashpots are not always reliable and frequently their time element changes with temperature.

(2) The pilot motor type is expensive in small sizes.

CURRENT LIMIT ACCELERATION

The current limit relay commonly used has a series coil. While the relay has a considerable range of adjustment, a number of series coils must be designed to apply the relay to the various sizes of motors.

Sometimes a larger motor and larger relays are installed than are actually required for a given application, either because the proper size is not known or extra capacity is desired. This may result in the use of relays with too few turns in the coil, making it difficult to adjust the acceleration to a low enough current value. Again, when the motors are large, the amount of copper used in the connections to the relays is considerable, also the heating of the coils is sometimes objectionable when they are in circuit much of the time.

To overcome these difficulties a relay employing shunt coils has been devised, the method used being the same as that employed for ammeters

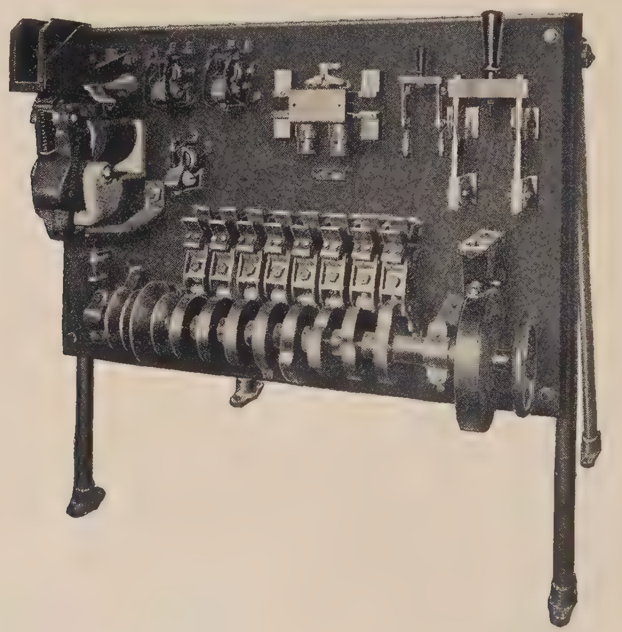


FIG. 68. Motor Operated Controller, Panel Mounted

This illustrates a motor operated controller of the panel type. Controllers of this design are used for time element where forced acceleration is required. This construction is very flexible and has a wide range of application. Motor is on rear of panel

with shunts, except that while for ammeters there must be inserted in the circuit a special shunt, across which the meter coils are connected, in the case of the relay a special shunt is not necessary, the coils being connected instead across the starting resistor.

Making this use of the starting resistance has another advantage, namely, that the shunt is shortened automatically by the closing of the accelerating contactors.

This reduces the voltage across the relay coils and permits the relays to be set for releasing at decreasing voltages and with a constant value of accelerating current, affording an automatic interlock to insure the operation of the relays in the proper sequence.

The relays can be held normally in the open position by mechanical connections to the accelerating contactors, which is the general practice when a series coil is used; or the relay coils may be energized in advance of the closing of the line contactor, thus permitting the relays to be mounted independent of the accelerating contactors. Several schemes have been devised for obtaining these results that have proved successful in practice.

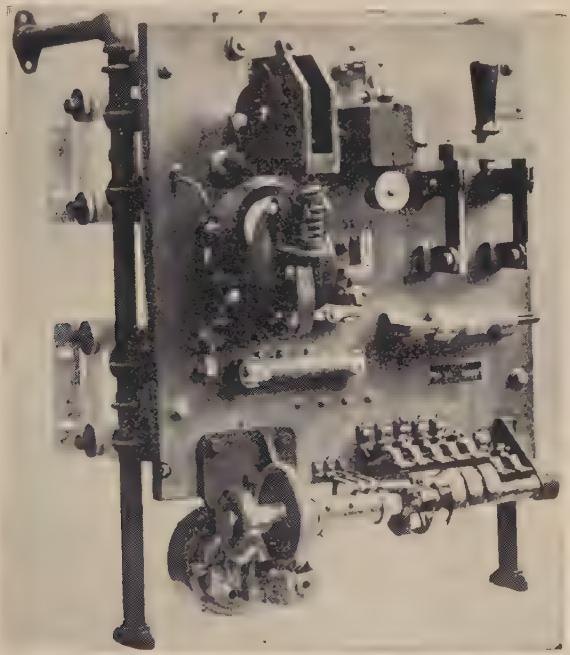


Fig. 69. Automatic Starter Control Board

Showing time element device consisting of a motor-operated drum controller

The heating of the relay coils may at first seem a disadvantage to the use of shunt coils. The same difficulty occurs with instruments and shunt wound motors; it can readily be taken care of by proper design. The coils are in the circuit only during the accelerating period and the temperature is not materially increased unless the operation is very frequent. Well designed relays operate at a very low wattage and, therefore, the normal temperature rise of the coils, even if connected continuously to the circuit, will not introduce much error.

One form of current limit relay is illustrated in Fig. 71. It consists of a double set of armatures. On one side of the coil are the accelerating armatures provided with contacts as shown in Fig. 72 as armatures *D, E,* and *F*. On the opposite side of the relay is the release armature *C*. The accelerating contacts are normally open, being held in this position by spring *H*. When the coil is magnetized the armature *C* closes, releasing the accelerating armatures *D, E* and *F*. These armatures, however, are held by the magnet against the spring *K*. By properly adjusting the air-gaps, these armatures release at different values of magnetism. Each armature closes a contact which energizes the coil on one of the accelerating contactors.

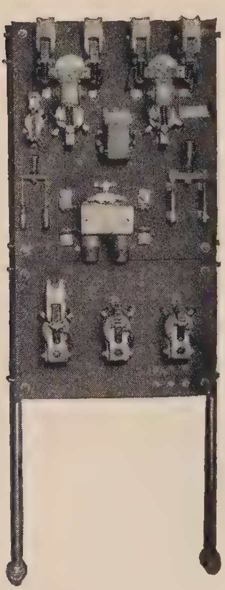


FIG. 70

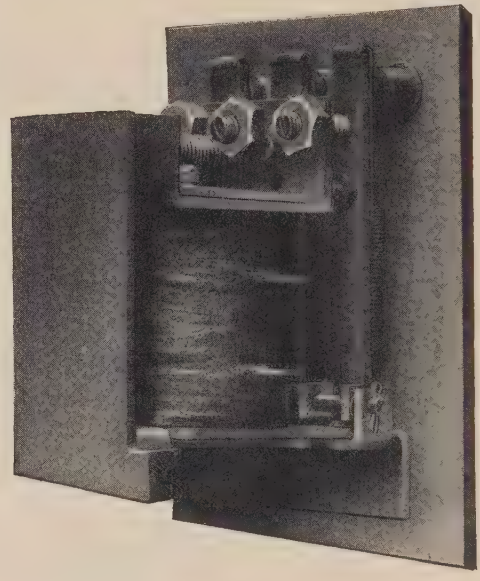


FIG. 71

FIG. 70. Reversing Controller with Dynamic Brake
Using the three-pole current limit relay illustrated in Fig. 71

FIG. 71. Three-Pole, Current Limit Relay
Operated by a shunt coil across the starting resistor

A typical scheme of connections for this relay is shown in Fig. 73. The relay is provided with two coils marked *A* and *B*. Coil *A* is connected across the starting resistor, coil *B* across the line. When the motor is first connected to the line, the armature is stationary and the full voltage drop is taken up by the resistor. Coil *A*, therefore, has full line voltage across its terminals. As the motor accelerates, the counter e.m.f.

of the motor reduces the voltage drop across the resistor and, therefore, the voltage on coil *A* decreases, releasing armature *F*. This closes contactor *2* which short-circuits a section of the starting resistor. The current immediately increases so that the drop at the instant of short-circuiting remains the same. The increased current causes the motor to accelerate to a higher speed, which in turn reduces the voltage drop across the remaining portion of the resistor, at the same time reducing the magnetism in the relay to a value which permits armature *E* to release. This closes contactor *3* which short-circuits an additional portion of the starting resistor. A further increase in the speed of the motor permits armature *D* to drop. This closes contactor *4* and short-circuits the starting resistor. The voltage across coil *A* is now zero, but coil *B* is still energized and furnishes sufficient magnetism to retain armature *C* in the closed position.

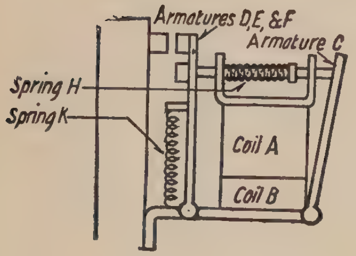


FIG. 72

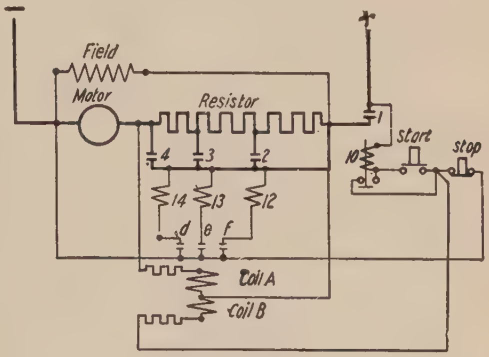


FIG. 73

FIG. 72. Diagrammatic Drawing of the Three-pole Relay Shown in Fig. 71

FIG. 73. Diagram of a Push Button Starter
Using the relay illustrated in Figs. 71 and 72

Fig. 73 shows a push button starter of a simple type. The closing of the start button energizes coil *10* and closes contactor *1*. This bridges out the start button contacts and permits the motor to accelerate as described above. If the stop button is pushed, the control wiring is disconnected momentarily, which opens contactor *1* and also coil *B* of the accelerating relay. This drops armature *C* and resets armatures *D*, *E* and *F* so that they are again ready for accelerating the motor.

The relay is designed so that the armature *C* closes at a relatively small value of magnetism; if the motor is started before it comes to rest, armature *C* will close, permitting armature *F* and possibly armature *E* to release, depending upon the speed of the motor, in the same way that a current limit relay control of the series type will immediately drop the accelerating relays on one or more contactors, if the current is below their holding value.

Relays may be actuated by gravity, by springs, or by a combination of both. A superficial consideration of the problem would indicate that the most desirable method of actuation is gravity. A careful consideration of the many applications indicate that a gravity actuated relay is sensitive to vibrations and must of necessity have considerable mass in the moving members. This makes a relay that is rather sluggish in operation for fast work, and one that is affected by its position of mounting and is sensitive to vibration. By designing the relay with very light moving parts, and using springs, a very reliable device can be produced, which is not seriously affected by the position of mounting or vibration and is very quick to respond to changed conditions. The relay shown in Fig. 71 is much faster than the contactors, Fig. 70, with which it is used, even when the contactors are made of pressed steel and have springs to give them quick motion.

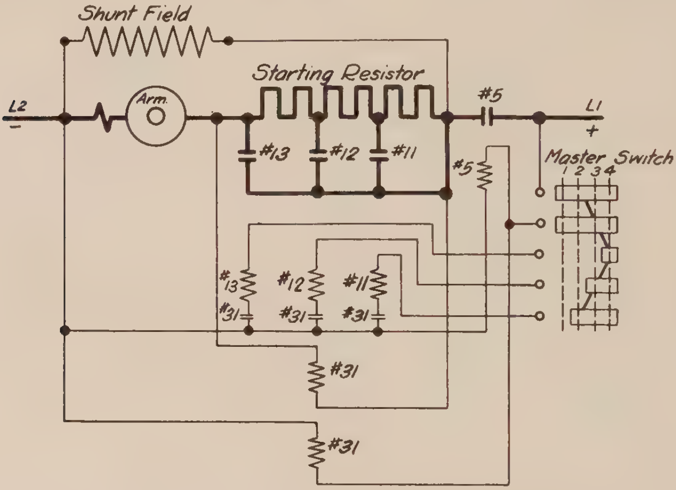


FIG. 74. Diagram of a Controller with Drum Master Switch and Relay Illustrated in Figs. 71 and 72

This diagram shows a method of controlling the amount of resistance in the armature circuit of the motor by moving the master switch from one notch to another

A further analysis of the action of this relay is given in Fig. 75. The upper curve shows the current taken by a motor during acceleration. The lower curve shows the voltage across the relay coils and, therefore, indicates the magnetism in the relay core, the ordinates representing voltage or magnetism and abscissae time. The time spacings in the two curves coincide. On the lower curve vertical lines are drawn, numbered *1. 2* and *3*. The heavy lines represent the voltage or magnetism at which the accelerating armatures release, the dotted lines show the voltage or magnetism at which they retrieve or pick up. If a drum master switch

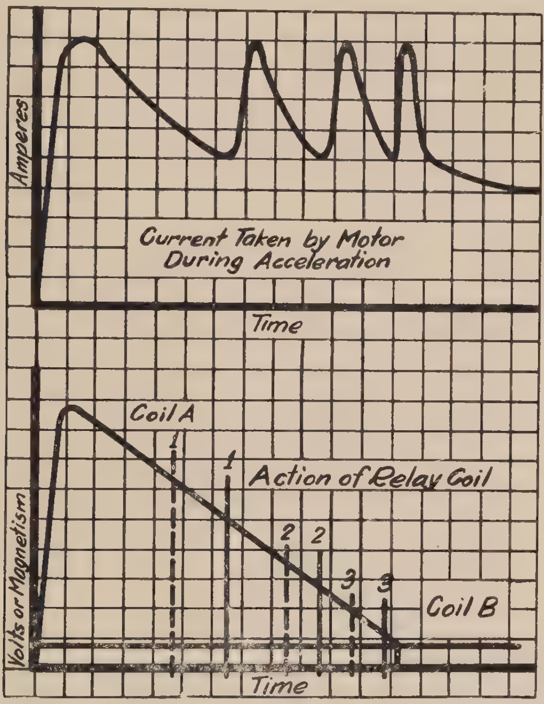


Fig. 75. Curve Showing the Voltage Time Current Relation when the Relay Shown in Fig. 71 Is Used

The upper curve shows the relation between time and the armature current of the motor. The lower curve shows the relation between time and the voltage across the relay coil. Since the magnetism in the relay is proportional to the voltage, this curve also shows the relation between time and the magnetism in the relay circuit. The two curves show the same time intervals so that the action of the relay is illustrated by the current curve. Both of these curves are only approximate in shape and have been simplified for the purpose of illustration

is used to obtain speed control, Fig. 74, the contactors short-circuiting the resistance may be connected or disconnected at the will of the operator. If the motor has been accelerated to full speed, and it is desirable to decrease this speed, the master switch is moved back several notches, releasing several of the accelerating contactors. This increases the voltage across coil *A* of the relay and causes it to retrieve or pick up the accelerating armature so that if the motor is again accelerated the automatic short-circuiting of the resistance takes place.

The windings for coils *A* and *B* are fixed by the line voltage and are independent of the size of motor in the same way that the windings of an ammeter are fixed by the voltage across the shunt, and calibration is changed by changing the shunt. The accelerating resistance for any particular motor must be selected to give the proper current control. If the load on the motor is changed, the resistor is also changed. The voltage across the total resistor is fixed by the line voltage and if the resistor steps are not properly proportioned, no relay will give smooth acceleration. The use of a shunt accelerating relay, has, therefore, the advantage that it can be adjusted once and need not be altered for any motor to which it is connected or the load on that motor. Since the relay responds to voltage only, it can be readily calibrated with a voltmeter. This is very much easier to do than to obtain the heavy current necessary to calibrate relays with series coils. The use of a small rheostat and voltmeter will enable an operator to check the calibration on any relay. The absence of mechanical connections between the relay and accelerating contactors makes it very easy to apply this relay to existing control equipment.

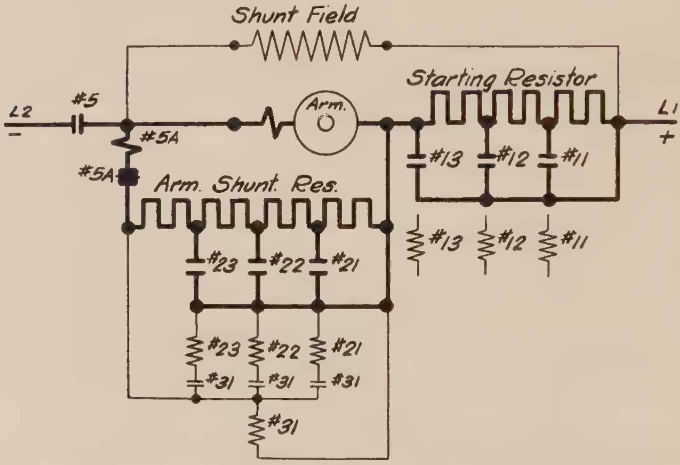


FIG. 76. Diagram Showing the Use of a Current Limit Relay to Obtain Automatic Deceleration

This is the same relay illustrated in Fig. 71 with one coil omitted

A relay of this type can be used to control deceleration by connecting the coil across the armature of the motor, Fig. 76. This permits the armatures D, E and F to drop out at decreased values of counter e.m.f., and actuate contactors, which short-circuit sections of the dynamic brake resistor. The connections to the relay coil can be closed by opening the line contactor.

CONCLUSIONS

The opinions of controller engineers differ as to the proper devices to use for controlling the acceleration of motors. The methods described are the ones usually employed. Various combinations of these devices are used and other means have also been employed. The best results depend upon the practical application for which the controller is designed. In general, the counter e.m.f. method is used for small motors, although it can successfully be employed for quite large units.

The series relay method is the most expensive, but very satisfactory, and should be used for heavy service, where the load varies throughout wide limits.

The series lock-out contactor is satisfactory for starting service where the acceleration is always under load. The last resistance switch is often provided with a holding coil to keep it from dropping out on light loads. Sometimes the last switch is operated by the counter e.m.f. of the motor and the preceding switches on the lockout principle.

The time element device is the most satisfactory to use where the voltage varies over wide limits, particularly where rapid starting is not necessary. This device in its various forms has been employed for many years, and at one time was the only means used for controlling the acceleration of a motor.

The current limit relay with shunt coils is simple and inexpensive, but is not as rugged as the series relay for some applications, nor as reliable for speed control or plugging control. It is sensitive of adjustment, and on light loads may accelerate too rapidly.

SUMMARY OF CHAPTER IX

TIME ELEMENT METHOD: In time element acceleration the starting resistor is short-circuited in a definite period of time without depending upon the fall of the starting current. The action of the short-circuiting device may be delayed by a dashpot, or the device may be operated by a pilot motor. The dashpot is subject to inherent mechanical limitations, the pilot motor is expensive for small controllers.

CURRENT LIMIT METHOD: In using the current limit relay with shunt coils, one coil (the holding coil) is connected across the line, the other (the calibrating coil) across the starting resistor. At starting the coils are energized and close the large or main armature, which releases mechanically three (or four) smaller armatures. These are still held open magnetically, but as the drop across the starting resistor decreases and the calibrating coil becomes deenergized they close at successively lower voltage values and actuate the accelerating contactors. After the calibrating coil is deenergized the main armature is held by the holding coil. Adjustment is by varying the air gap and spring tension. A rheostat and voltmeter may be used to check the calibration.

CHAPTER X

STARTING CHARACTERISTICS OF MOTORS WITH DIFFERENT METHODS OF CONTROL

Testing with (1) meters, (2) oscillograph, (3) spark gap—motor starting characteristics, d-c.—results of oscillograph tests—motor starting charactersitics, a-c.—use of spark gap in tests—future investigations.

THE usual method of testing motors and controllers has been to use an ammeter and a voltmeter. These instruments gave good average readings, but due to the inertia of their indicating member, only average values could be obtained. However, the improvement in the oscillograph and its general adaptation to commercial work has made possible the determination of many factors, which are not shown by an ammeter. In some cases even the oscillograph has not been rapid enough to indicate excessive conditions of voltage and a spark-gap has been used. Considerable practice is required to obtain good results with an oscillograph and experience is required in reading these results. Investigations of this kind have proved valuable and in many cases mechanical analyses have been made, explaining in detail the phenomena observed with the oscillograph.

Direct-Current Motor

The simplest form of motor and control, as well as the oldest, is the direct-current shunt motor with a controller which short-circuits the armature resistance during acceleration. When this combination was first used, care was necessary in accelerating the motor, to prevent excessive sparking or flashing. The starter was operated by hand and had a considerable number of steps.[1] This was necessary to cut down the burning on the different steps and to introduce a time element, so that the operator, if he were careless, would not short-circuit the starting resistance too rapidly. Due to this practice, engineers have become accustomed to quite a number of starting steps in accelerating these motors. They have based their calculations of the accelerating current peaks on Ohm's law and have neglected a number of other factors which enter into this problem. The use of circuit breakers or overload relays without a time element attachment has also tended toward the use of a considerable number of starting steps, in order to prevent their tripping on the overload peaks which occur.

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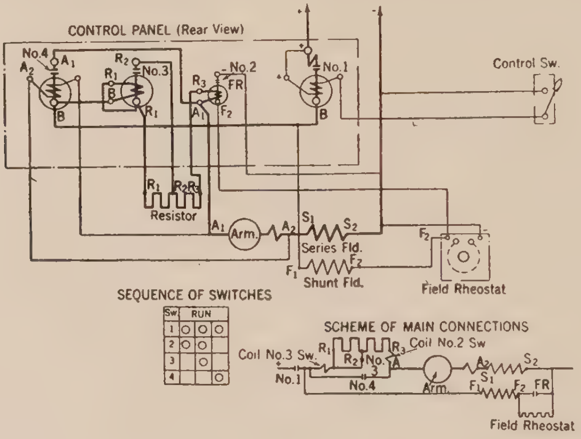
[1] Such a starter is shown in Figs. 33 and 34.

The introduction of the magnetic contactor has provided a method of switching electric currents of considerable energy without the rapid destruction of the contact. The contactor can be used in connection with automatic devices for short-circuiting the resistance during acceleration, which eliminate the personal element and prevent careless manipulation. The use of contactors for automatic acceleration immediately reduced the number of starting steps, as compared with the manually operated starter. A feeling still exists that several steps are needed when starting even small motors. In order to obtain some actual information, a series of tests was made with an oscillograph on a direct-current motor accelerated automatically and belted to a generator of about double the motor size. A record was made of the armature current, the armature voltage, and the field current. In a few cases a Prony brake was used for loading the motor instead of belting it to a generator.[2] The diagram of connections is given in Fig. 77, and Figs. 78 to 85 show results of some of the tests. The internal resistance given in the captions includes the complete resistance of the controller and motor armature circuit, also the leads between the motor and controller. It was measured from the + to the — terminals of the controller with the starting resistance short-circuited. In addition, as will occur in any installation, there was some resistance in the lead wires between the controller and the source of power.



Sw	RUN		
1	○	○	○
2	○	○	
3		○	
4			○

FIG. 77. Diagram of Connections of Automatic Control Equipment
Used in tests to analyze the starting characteristics of motors

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[2] The results of these tests appeared in the *Proc. A.I.E.E.*, Feb., 1917, p. 233.

The 50-kw. direct-current generator belted to the motor represents more intertia than usually occurs in practice. Figs. 78 to 83 cover a period of about two seconds. Figs. 84 and 85 cover a period of about four seconds.

SUMMARY OF TESTS[3]

1. It seems unnecessary, with automatic acceleration, to use more than one intermediate step in short-circuiting the armature resistor used with small motors except where special requirements are to be met. It is practicable to use one switch with motors as large as 15-hp. for general purposes and operate this switch by counter e.m.f. setting the switch to close at 75 per cent of normal voltage.

2. If the motor field is zero, or has a small value when the line switch is closed, the starting torque is also zero or has only a small value and it will increase gradually so that the motor, or its load, will not be subjected to a heavy shock or jar when the lost motion in the drive is taken up.

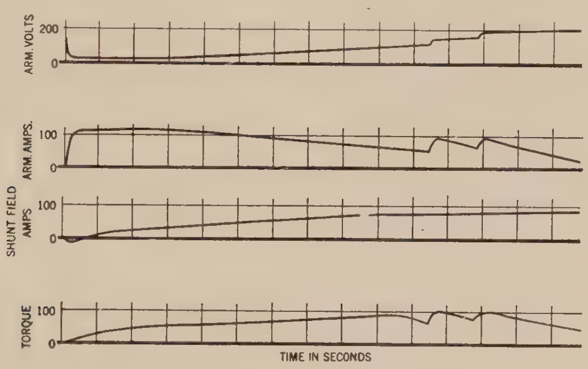

Fig. 78. Starting Tests of a 20-hp., 750-r.p.m. Motor Belted to 50-kw. Generator with no Load on the Generator

Resistance 1.35 ohms starting + 0.25 ohm internal. The starting resistance was short-circuited in two steps at 120 and 160 volts counter e.m.f.

3. The shunt field of small 2 to 1 adjustable speed motors can be reduced in one step under normal load conditions without fear of undue torque or current. This practice can be safely followed with 50-hp. motors and perhaps larger. This covers the usual range of sizes for this type of motor. Most machine tool motors are started light. Under this condition, the motor can be started successfully with minimum field strength and the field relay omitted. This will enable the use of the same controller for constant speed and adjustable speed motors, supplying a separately mounted field rheostat for the latter.

4. Adjustable speed motors can use one step of resistance for dynamic braking as the change in field strength tends to maintain the braking current constant over a considerable range of speed.

5. The time required to accelerate to 95 per cent of speed is very short. In these tests the time did not exceed three seconds.

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[3] From the author's A.I.E.E. paper, *loc. cit.*

During the discussion of these tests, it was pointed out that the results obtained may have been materially affected by a drop in line voltage. It was admitted that some drop in line voltage would probably occur in most installations. The effect that the use of a small number of starting steps would have if the motor and controller were located close to the power house was, however, questioned. In order to determine this point, the writer had a number of tests made with the motor connected to the bus-bars in the power house; an oscillograph record was taken of the armature amperes, armature volts, and line voltage. The tests showed that there was practically no change in the line voltage during acceleration and that the current peaks obtained were about two-thirds of the value, as usually calculated, based upon Ohm's law. The results of these tests are shown in Figs. 86 and 87.

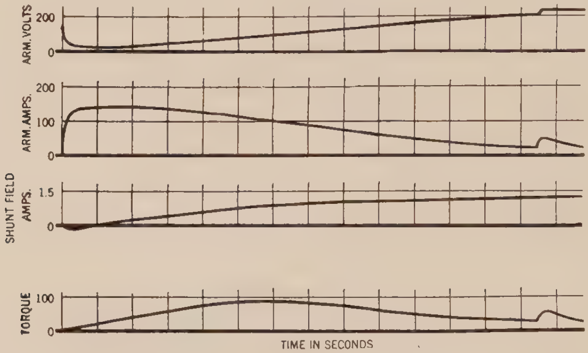

FIG. 79. Starting Tests of a 20-hp., 750-r.p.m. Motor Belted to a 50-kw. Generator, with No Load on the Generator

Resistance one ohm starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 190 volts counter e.m.f.

In calculating the starting resistance for a shunt motor, the steps are usually arranged in geometrical progression. This method is based on the assumption that each step of resistance is short-circuited when the motor current has reached a uniform minimum value. This value is that necessary to overcome the torque which the motor is required to develop during the accelerating period. During these tests, a standard 15-hp., 230-volt, 825-r.p.m. shunt motor was accelerated under full load obtained by means of a Prony brake. The minimum accelerating current to overcome this torque was 50 amperes. The line voltage was 258 volts and the resistance was short-circuited in one step. Following the usual method of calculation, and assuming two equal current peaks, a calculated external resistance of 0.905 ohm would be required in series with the motor armature. This would give two equal peaks of 220 amperes each. The oscillograph record of this test, shown in Fig. 86, was obtained with 1.282 ohms in series with the armature and shows maximum current peaks of 168 amperes at start and 163 amperes when the resistance was short-circuited. This short-circuit occurred when the counter e.m.f. across the motor brushes was 61.5 volts. This voltage divided by 0.268 ohm, which is the internal resistance, would give a peak of 230 amperes. By extending the current peak to the instant when the resistance switch closed, the curve shown by dotted lines in Fig. 86 gives a close check upon the calculated value of current. The effect of the armature self induction is shown by the difference between the dotted line and the heavy line. The starting peaks are thus shown to be about two-thirds of the calculated value using the geometric progression method and neglecting armature reaction.

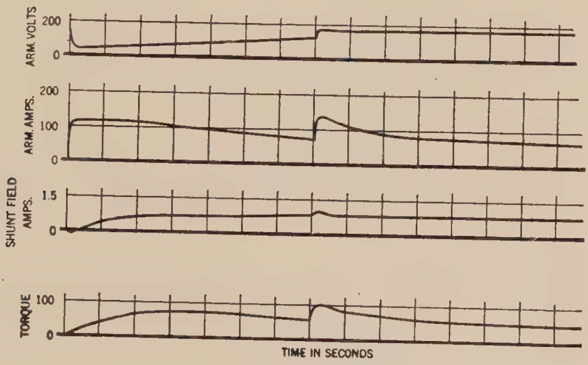

FIG. 80. Starting Tests of a 20-h.p., 750-r.p.m. Motor Loaded with a Prony Brake Set for Full-load Torque at Full Speed

Resistance 0.725 ohm starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 125 volts counter e.m.f.

In Fig. 87 is shown the results of a similar test, accelerating with one-half full-load torque applied by Prony brake. The peak calculated in the usual way would require 138.6 amperes based on a minimum accelerating current of 20 amperes. The actual peaks obtained were 110 and 102 amperes, showing the calculated peak to be about 31 per cent in excess of the actual value.

The following mathematical analysis has been worked out for calculating the true current peak shown in Figs. 86 and 87.[4] By taking into account inductance and inertia, it is possible to calculate the true peak current when a portion of the external series resistance is short-circuited. The differential equation for the transient current is

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[4] By Mr. A. A. Gazda, who made these tests.

$$L\frac{di}{dt}+M\frac{di}{dt}+Ri+K_1\int idt=E.$$ [5]

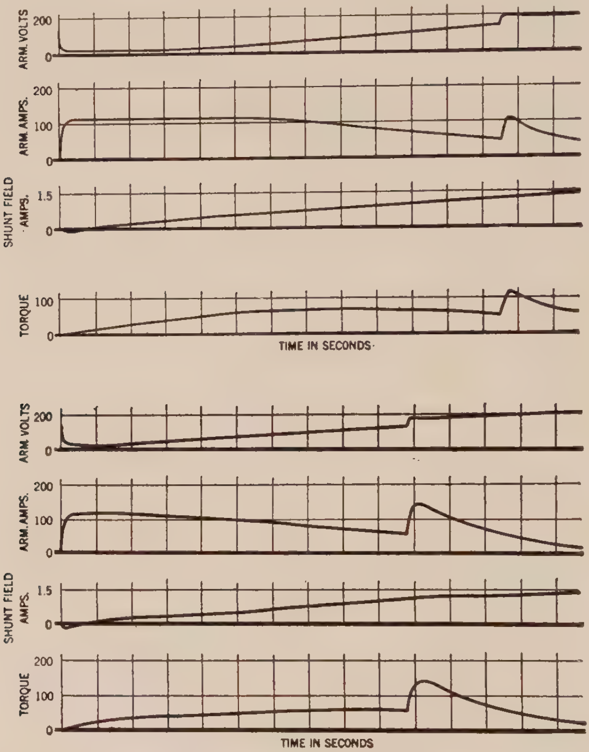

FIG. 81. Starting Tests of a 20-hp., 750-r.p.m. Motor Belted to a 50-kw. Generator, with No Load on the Generator

Resistance 1.35 ohms starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 150 volts counter e.m.f. for the upper set of curves and at 120 volts counter e.m.f. for the lower set. The adjustment for the upper curves gives equal current peaks and represents a practical controller

The effect of mutual inductance M is very small and can be neglected. On the other hand, the counter torque T_c will be considered and assumed constant; hence,

$$L\frac{di}{dt}+Ri+K_1\int idt-K_2\int T_c dt=E.$$

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[5] Starting characteristics of Direct-current Motors, K. L. Hansen, *Proc. A.I.E.E.*, Feb., 1917, p. 272, Eq. 22.

Since we are considering the case in which the motor has come up to some percentage of full-load speed and a part of the series armature resistance is short circuited, the initial counter voltage of the motor must be added to the left hand side of the above equation giving

$$E_1+L\frac{di}{dt}+Ri+R_1\int i\,dt-K_2\int T_c\,dt=E.$$

The general solution of this equation takes the form

$$i=A_1+A_2\epsilon^{\frac{-R+\sqrt{R^2-4LK_1t}}{2L}}+A_3\epsilon^{\frac{-R-\sqrt{R^2-4LK_1t}}{2L}}$$

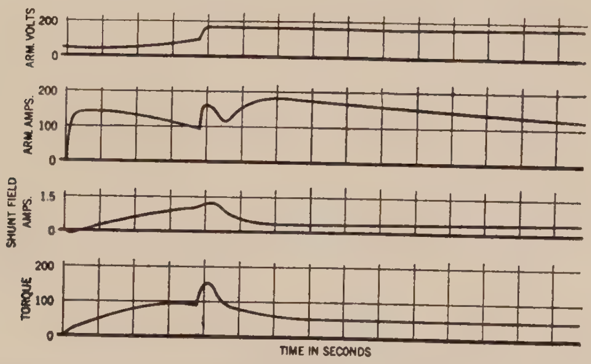

FIG. 82. Starting Tests of a 20-h.p., 500–1500-r.p.m. Motor Belted to Two 50-kw. Generators Connected to Give 20-hp. Torque at 1500 r.p.m.

Resistance 0.76 ohm starting + 0.34 ohm internal. The starting resistance was short-circuited in one step when the counter e.m.f. was 100 volts. The field resistance was inserted when the starting resistance was short-circuited, the gradual rise of current being due to weakening the field

in which A_1, A_2 and A_3 are constants of integration. The value of these in terms of known quantities when the motor is accelerating under a constant resisting torque is

$A_1=I=$the initial current.

$$A_2=\frac{I(R_s-R)}{\sqrt{R^2-4LK_1}};\qquad A_3=\frac{I(R_s-R)}{\sqrt{R^2-LK_1}}.$$

$R_s=$series resistance that is short circuited.

$R=$final resistance.

When $4LK_1$ is greater than R^2, the current oscillates around the value required for the constant torque load, and the above general solution becomes

$$i=I+\frac{2I(R_s-R)}{\sqrt{4LK_1-R^2}}\left(\sin\frac{\sqrt{4LK_1-R^2t}}{2L}\right)\times\epsilon^{\frac{-Rt}{2L}}.$$

The values of current represented by this equation were calculated for the period immediately following the closing of the accelerating switch, as shown in Figs. 86 and 87. These values check the oscillographic curve very closely and are shown in Table I. This brings out the feasibility of calculating the actual peak current during the acceleration of the motor by means of series resistance.

TABLE I

Accelerating Current Values

Time in Seconds	Amperes at Half Load Torque (Fig. 48)	Amperes at Full Load Torque (Fig. 47)
0.00	20	50
0.01	76	120
0.02	104.4	153.5
0.03	112.8	166
0.04	107.5	151
0.06	83.2	129
0.08	54.2	93
0.10	33.0	56.3
0.123	20	50
0.14	16.5	45.5
0.16	15.7	45
0.18	16.9	46
0.24	20	50

Time is calculated from the instant that the resistance short-circuiting switch makes contact.

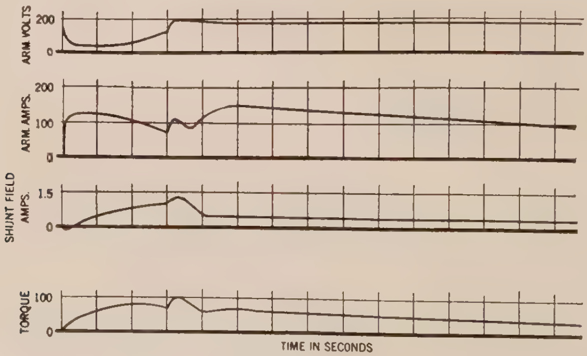

Fig. 83.

Same data as Fig. 82, except a Prony brake was used instead of the generator to give full load at 1500 r.p.m. This gives a heavier starting torque and less inertia. The starting resistance was short-circuited at 120 volts counter e.m.f.

These last tests confirm the writer's opinion that only a small number of starting steps are required in accelerating a modern direct-current shunt motor under ordinary conditions. Where a compound or series motor is used, the starting torque will build up more rapidly, particularly with the series motor, so that this may prove a limiting condition during acceleration.

A number of tests were made upon a reversing planer equipment to obtain a detailed analysis of the different parts of the operation. These curves, one set of which is shown in Fig. 88, proved of considerable interest and value in designing these controllers.

ALTERNATING CURRENT SQUIRREL-CAGE MOTORS

Under certain conditions an excessive current may be obtained in starting alternating-current squirrel-cage motors.[6] These conditions are not apt to occur in the smaller size motors commonly used. The increasing use, however, of large size motors of this type, particularly with two and four poles, has made it necessary to consider these phenomena

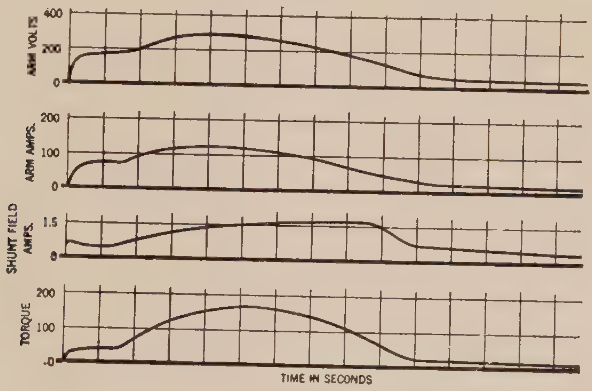

FIG. 84. Effect of Field Variation on Dynamic Braking

Made with a 15-hp., 400–1600-r.p.m. motor belted to a 50-kw. generator with no load on the generator. When the motor was operating at 1600 r.p.m. the armature was disconnected from the line and connected to a resistance to give dynamic braking. At the same time the motor field rheostat was short-circuited, strengthening the field to the 400-r.p.m. value. The curves show that the field built up faster than the speed decreased so that the armature voltage at first increased and then remained practically constant for a considerable period. A strong dynamic brake was thus maintained until the motor speed was quite low so that it could be easily stopped by friction or a mechanical brake and shown the importance of analyzing the motor and controller as a unit.

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[6] See paper on "Transient Conditions in Asynchronous Induction Machines," by Mr. R. E. Hellmund, *Proc. A.I.E.E.*, Feb., 1917, p. 205.

Several years ago, a series of breakdowns in the insulation of a wound-secondary motor occurred, due to the inductive effect between the windings when the secondary circuit was opened before the primary winding was disconnected from the line. Oscillograph tests at first did not disclose this difficulty but the use of the spark gap showed that approximately five times normal voltage might be obtained in the secondary circuit under these conditions. Prior to that time, it was the general belief that an alternating-current motor had very little inductive effect of this kind.

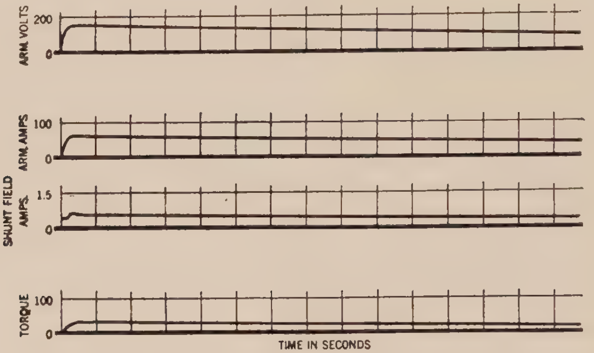

FIG. 85. The Same Arrangement as Fig. 84

Except that the motor field was not increased but remained at the 1600-r.p.m. value, showing that a decreasing torque with decreasing speed will cause considerable drift before the motor comes to rest

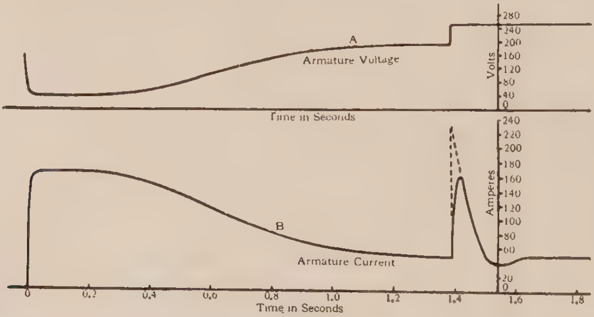

FIG. 86. Starting Tests of a 15-hp., 825-r.p.m. Motor Driving a Prony Brake Set for Full-load Torque

Starting resistance 1.282 ohms + 0.268 ohm internal resistance. The starting resistance was short-circuited in one step when the counter e.m.f. was 161.5 volts

FUTURE INVESTIGATIONS

The writer believes that there is an opportunity for considerable valuable work to be done along this line by universities and technical schools.

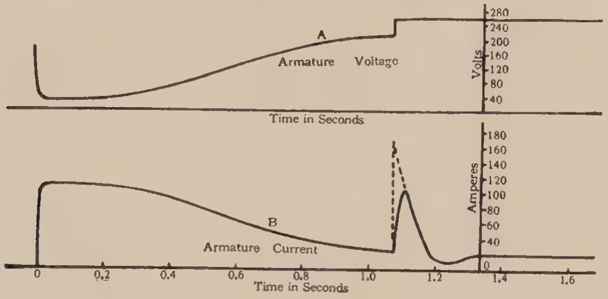

FIG. 87. Same Starting Test as Fig. 86

Except that the Prony brake was set for one-half full-load torque. The starting resistance was 2.062 plus an internal resistance of 0.268 ohm

Most of their laboratories are equipped with oscillographs and other means for this kind of investigation. The work is very interesting and

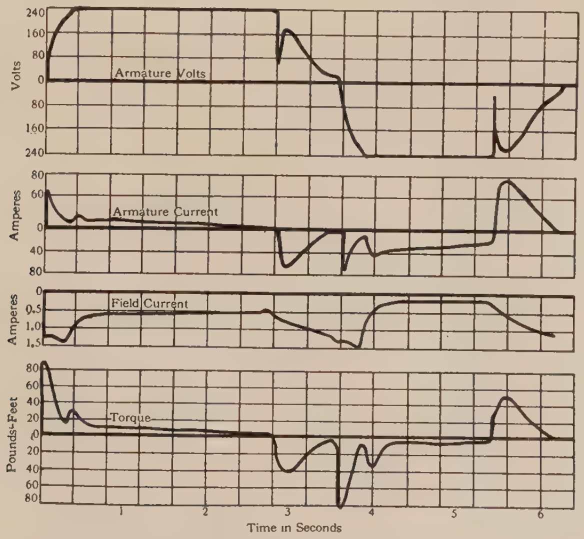

FIG. 88. Starting Tests of a 20-hp., 250–1000-r.p.m., 230-volt Shunt-motor Operating a Planer

Twenty-four inch tool travel, 500-r.p.m. cut and 1000-r.p.m. return stroke. Beginning at the left, the motor is accelerated for the cutting stroke, then dynamic braking occurs, followed by acceleration for the return stroke. The last loop is dynamic braking from the return stroke instructive; in the foregoing description only the more important phenomena have been discussed. An analysis of the curves shows that the armature voltage is approximately equal to the line voltage at the instant of closing the circuit. The shunt field amperes start at zero and at first have a negative value, probably due to the reactive effect of the armature current. The peak values of the armature current show a round-off due to the reactive effect of the circuit. This can be varied by changing the mechanical inertia of the parts or by changing the inductance of the complete circuit. The shunt field is assumed to follow the field current quite closely, although it undoubtedly does not reach the instantaneous values shown by the curve of field amperes. Further investigation in this line would be interesting.

SUMMARY OF CHAPTER X

In testing a motor and control with an ammeter and voltmeter, only average values can be obtained, due to the inertia of the indicating member. Many additional factors can be determined by the use of the oscillograph. To check excessive transient a-c. voltages, a spark gap may be used.

With the old d-c. starter, which shunted out sections of the armature starting resistance by hand, a number of steps were required. Oscillograph tests have shown that with magnetic contactors fewer steps are necessary. One intermediate accelerating switch, closing at 75 per cent of normal voltage, seems sufficient for motors up to 15 horse power.

If the motor field is allowed to build up from zero at the same time that the line switch is closed, the starting torque increases gradually and a heavy shock to the driven machinery is avoided.

The shunt field of two to one adjustable speed motors up to 50 horse power can be reduced in one step.

Satisfactory dynamic braking for adjustable speed motors can be obtained with one step of resistance.

Motors up to 50 horse power can be accelerated to 95 per cent of full speed in three seconds.

In a-c. motors, due to the inductive effect between the primary and secondary circuits, as high as five times normal voltage may result when the secondary circuit is opened while the primary is connected to the line.

CHAPTER XI

METHODS OF SPEED CONTROL AND DYNAMIC BRAKING

Speed control of varying speed d-c. motors—of adjustable speed d-c. motors—variable voltage system—speed control of varying speed a-c. motors—of adjustable speed a-c. motors—dynamic braking, d-c.—dynamic braking, a-c.

Direct-Current Varying Speed Motors

Variations in the speed of a direct-current motor can be obtained by changing the voltage across the motor brushes. Usually this is accomplished by placing a resistor in series with the armature, as shown in Fig. 89. The drop in voltage through the resistor is equal to the resistance multiplied by the current. If the line voltage remains constant, the speed of the motor can be varied by changing either the ohmic resistance or the load. The characteristic curves for direct-current shunt, compound and series motors are shown in Fig. 90. Curve *A* is for a shunt motor. The difference in speed between full load and no load is caused by the drop in voltage due to the internal resistance of the motor. The amount of change in speed is called the regulation of the motor, which may be expressed by giving the speeds at no load and full load or as a percentage change in speed. The shunt motor is assumed to have a constant field strength, and therefore the change in speed is small. If, however, a resistor is placed in series with the armature, a curve such as *AA* is secured, which shows considerable reduction in speed at full load, the amount of speed reduction depending upon the resistance in series with the armature. In this case, it can readily be seen that the speed of the motor depends upon the load and will vary with different values of torque. It is for this reason that these motors are called varying speed motors.

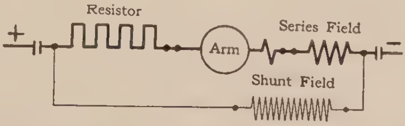

Fig. 89. Diagram of Connections for Varying the Speed of Direct-current Motors Using a resistor in series with the armature

If part of the field winding is made up of series turns, the field strength will increase with increased torque, so that the difference between no-load and full-load speed is quite marked, as shown by curve *B*. If external resistance is used, a curve such as *BB* results. This curve can be changed by varying the amount of resistance in series with the armature. Curve *C* shows the regulation curve of a series motor. Theoretically, at no load, there is zero field strength and therefore infinite speed. It is therefore necessary to have a definite load on a series motor to prevent its running away and series motors should not be used for any applications where the load is reduced to a very small value. Usually 25 per cent of full load is required to keep the speed within safe limits. If a resistor is used in series with the armature, curve *CC* results, which can be varied by changing the resistor.

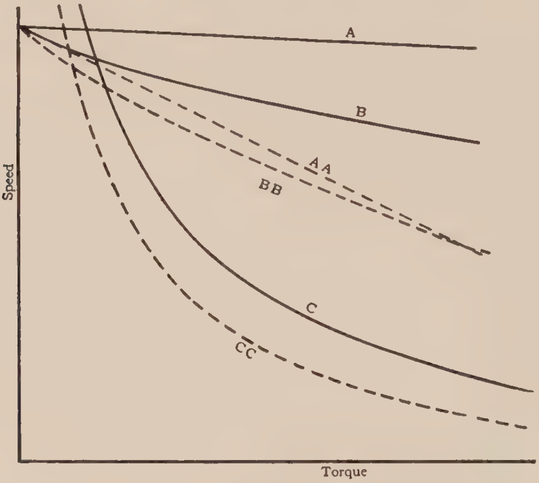

FIG. 90. Characteristic Regulation Curves of Direct-current Motors

Using the series resistor scheme of Fig. 89

It will be seen from these curves that the series motor is best adapted for speed regulation by the use of series resistance, the slope of its curve being much steeper than those for the shunt or compound motor. Where the load may become very light at times, it is necessary either to make a special arrangement for energizing the series field, as will be explained later, or to use a compound motor. The curve for the compound motor will vary between that of the series and shunt motor, depending upon the percentage of compounding used.

With this method of speed control, it is necessary to change the amount of armature resistance to obtain the correct speed with a changing load.

This at first sight may seem to be rather complicated, but in practice the operator can move his controller lever forward or back until the desired speed is obtained.

Where it is desirable to regulate the speed of the motor within closer limits, the arrangement of resistors shown in Fig. 91 is used, where *RA* is a resistor in series with the armature and *RS* is a resistor in shunt with the armature. This is known as a combined armature series and shunt resistance control. If *RS* has a very low ohmic resistance, the speed of the armature can be held at a low value throughout its range of load. Fig. 92 shows the various curves for this arrangement. Curve *1* is the armature current. Curve *2* is the line current, and curve *3* is the shunt current passing through the resistor *RS*. Curve *4* is the speed-current curve for the motor connected directly to the line. It can be seen from these curves that the motor performance is somewhat similar to a badly regulated shunt motor. At no load, the series field obtains current through the resistors *RA* and *RS* so that the speed of the motor has a fixed value. The speed can be changed by varying either *RA* or *RS*.

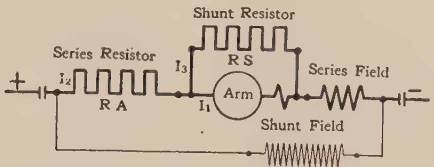

FIG. 91. Diagram of Connections for Speed Regulation

Using the combined series and shunt resistance control method

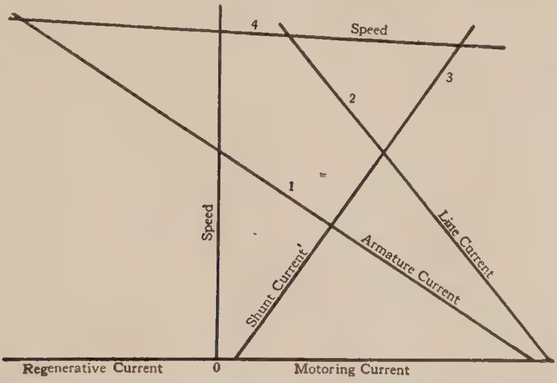

FIG. 92. Characteristic Curves of Direct-current Motors

Using the control scheme Fig. 91

Sometimes both are changed simultaneously. In figuring the speeds obtained with this arrangement, the circuit is rather complicated and the problem can be simplified by drawing curves similar to the ones shown in Fig. 53. Two points in these curves can readily be determined. The armature and line current can be found for zero load and for zero speed. The shunt current in resistor *RS* can be figured from these two values.

Direct-current Adjustable Speed Motors

Neglecting the internal resistance of the armature and assuming that the number of conductors on the armature is fixed, the speed of the motor will depend upon the strength of the field, providing a constant voltage is maintained across the armature brushes. If the motor is shunt wound and a rheostat is placed in series with the field winding the current can be changed and the motor caused to operate at different speeds. The speed of the motor will be practically constant for whatever value the rheostat is adjusted and will not vary under changing loads. For this reason, the motor is called an adjustable speed motor. There will be a small change in speed between no load and full load, due to the drop through the armature resistance. This change in speed, however, is usually negligible for most applications. The amount of speed range that can be obtained on a given motor depends upon the iron in the magnetic circuit. The slowest speed is obtained with the maximum field strength. This field strength, of course, reaches a limit when the iron in the magnetic circuit becomes saturated. The maximum speed is obtained with the weakest permissible field strength. This can be reduced only a limited amount, as sufficient field must remain to give stable operation of the motor. To obtain a wide speed range by field control involves considerable expense in the motor and usually a maximum of four to one is all that is attempted commercially.

For many applications, the combination of armature resistance and field control is used. The slow speeds are often required only for short intervals of time or at reduced loads, so that the loss in armature resistance is small.

Direct-current Motor Variable Voltage Control System

If a separate generator is provided for each motor, the speed of the motor may be altered by changing the field strength of the generator. This alters the voltage of the generator and the motor has a speed corresponding to the generator voltage. The generator field may be reversed to reverse the rotation of the motor. Very slow speeds can be obtained and the speed remains fairly constant between no load and full load. In the past this method of control has been for large motors of several hundred horse-power, being particularly adapted for reversing service, such as for large mine hoists and reversing steel mills, but recently has been successfully extended to smaller motor installations such as elevators, reversing planers, etc. The controller is small and inexpensive, as only the field current of the generator is manipulated. It is the practice to connect the generator and motor armatures in a closed circuit provided with a single overload circuit-breaker, which is opened only in cases of emergency.

Sometimes this arrangement of control is combined with a motor having a two to one speed range, so that higher speeds can be obtained for certain operations. The initial cost of this combination is less than for the constant speed motor, as it does not add a great deal to the cost of the motor to obtain the additional increase in speed, and a smaller generator can be used than if the entire speed range were obtained by varying the generator voltage.

A more detailed discussion is given in a later chapter.

ALTERNATING-CURRENT VARYING SPEED MOTORS

The relation between the speed and torque of an induction motor having a wound secondary with collector rings is shown in Fig. 93. When the collector rings are short-circuited, the speed of the motor decreases very little from no torque to the maximum torque. When this point is reached, the speed of the motor drops abruptly and continues to decrease until zero speed is reached. If, however, the torque is sufficiently reduced, the motor will again increase in speed until it is very close to full speed. The curve shows that there is a maximum torque which the motor is capable of exerting and that, if this torque is exceeded, the motor will stop. This maximum torque is usually called the "pullout torque" of the motor. The drop in speed from no load to maximum load is small and compares with that of the direct-current shunt motor. This drop in speed is due to the internal resistance of the motor.

If resistance be introduced in the secondary circuit of the motor, the slope of the speed curve is increased, so that the difference in speed between no load and maximum load is considerable, as shown in curve *2*. Sufficient resistance can be used to bring the speed to zero at the maximum torque, as shown in curve *3*. With a still further increase in resistance of the secondary, curve *4* results. These curves are typical, and any particular curve desired can be obtained by adjusting the resistance in the secondary circuit of the motor. If a controller is arranged for varying the resistance in the secondary of the motor, the speed of the motor can be adjusted to any required value at a given torque. The speed, however, will change with the torque, and for that reason the motor is called a "varying speed motor."

When the motor is started from rest it may not commence to rotate on the first notch of the controller, and the operator will therefore move the controller handle to the second notch to reduce the resistance in the secondary; this reduction of resistance will increase the starting torque by changing the shape of the curve up to the point of maximum, as shown in curve *3*. If the resistance is reduced still further, the current will increase, but the torque will decrease, as shown in curves *2* and *1*. It will therefore be seen that care must be exercised in starting these motors under heavy load to prevent reducing the resistance in the secondary beyond the value for maximum torque.

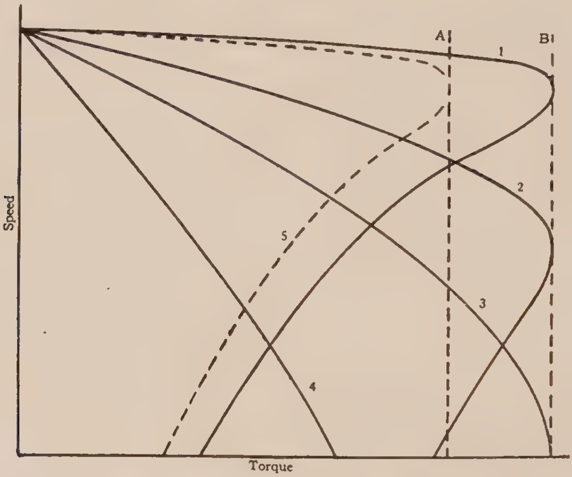

FIG. 93. Typical Speed-torque Curves of a Wound-rotor Induction Motor Obtained by varying the resistance of the secondary circuit

The speed of the motor at no load is called the synchronous speed. When the motor is loaded the actual speed of the motor is less than the synchronous speed. This difference in speed is called the "slip" of the motor. The curves show that this slip in speed is dependent upon the resistance in the secondary circuit.

The torque of the motor is proportional to the square of the voltage. A reduction of 10 per cent in voltage reduces the torque to 81 per cent of its maximum value, or the pull-out torque of the motor is reduced from the dotted line *B* in Fig. 93 to the dotted line *A*. The speed torque curve of the motor with short-circuited secondary and 90 per cent normal voltage is shown by the dotted curve *5*. Thus the output of a crane or hoist is often seriously affected by poor voltage regulation. It may happen that when the voltage regulation is poor the motor will fail to start its maximum load from rest.

If the motor is provided with a high-resistance secondary, as shown in Fig. 94, curve *1*, which is a speed torque curve similar to curve *3* in Fig. 93, the speed of the motor may be regulated by reducing the primary voltage, as shown in Fig. 94, curves *2*, *3* and *4*. This method has been employed, but has the disadvantage of giving reduced torques at decreased voltages. Usually the motor is required to exert as much torque at the slow speed as at the high speed, and therefore this method is seldom used. The method in universal use at present for varying the speed of induction motors is to maintain the primary voltage constant and change the resistance in the secondary of the motor.

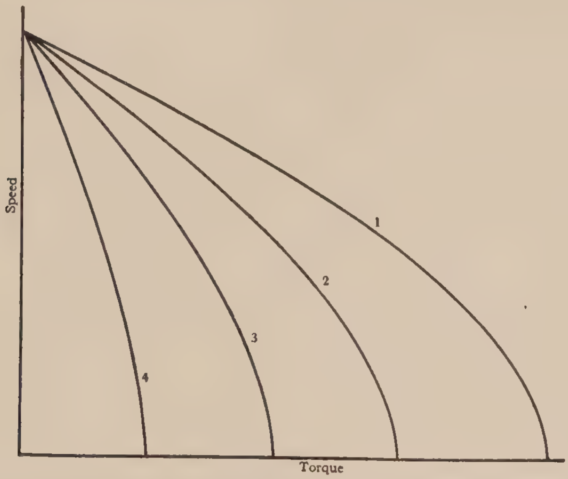

FIG. 94. Typical Speed-torque Curves of a Squirrel-cage Induction Motor Obtained by primary voltage control

There are several other methods of controlling the speed of the slip-ring induction motor, some of which are applicable only to large motors. They consist in connecting the slip rings of the motor to some source of voltage supply, the voltage and frequency of which can be varied. These methods of control are not yet in common use.

ALTERNATING-CURRENT ADJUSTABLE SPEED MOTOR

The best-known means at present for adjusting the speed of alternating-current motors is to change the number of poles in the primary.

Quite frequently motors are built having two sets of poles, one set giving high speed and one set slow speed. Usually these motors are provided with squirrel-cage secondaries, but slip-ring motors also have been built of this type, particularly for elevator and hoist work. The controller consists of a double-throw switch or its equivalent for changing the connections of the motor primary, so as to give the desired number of poles.

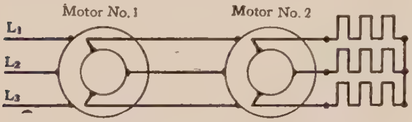

FIG. 95. Cascade Connection of Induction Motors for Speed Regulation

Another method, which is equivalent to changing the number of poles, consists in connecting two motors in cascade, the secondary of the first motor being connected to the primary of the second, as shown in Fig. 56. Let us consider that the first motor is wound with six poles and the second motor with four poles. These motors can be connected together, so that they have a combined speed equivalent to the sum or difference of the poles, which would be a ten-pole or a two-pole speed. Either motor can be operated separately as a six-pole or a four-pole motor. With this combination it is possible to get a speed equivalent to two, four, six and ten poles. It is necessary that both motors be mounted upon a common shaft or rigidly coupled together. Arrangements of this kind have been used in a number of cases, particularly with large motors.

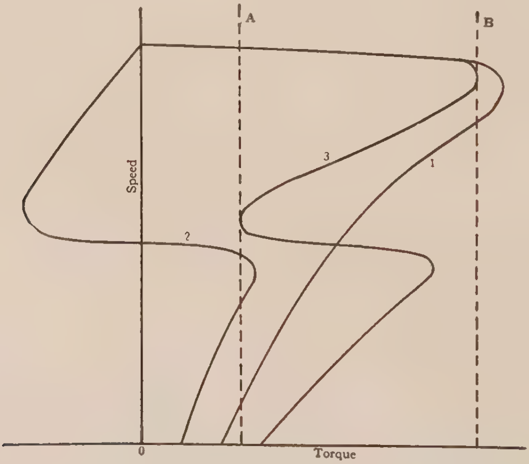

FIG. 96. Typical Speed-torque Curves of a Polyphase Motor Having a single-phase secondary winding

In a later chapter other methods of adjusting the speed are described.

A special condition of operation exists in the slip-ring type of induction motor when one phase of the secondary circuit is open. This gives a single-phase circuit only in the secondary, and the motor operates at approximately half speed over quite a range of load. The explanation of this is shown in Fig. 96. Curve *1* represents the standard speed-torque curve set up by the primary, and curve *2* the speed-torque curve of the single-phase secondary. Curve *3* is the resultant of *1* and *2*. As curve *2* passes through zero speed it approaches a horizontal position, and therefore a slight change in the speed of the motor results in a considerable change in torque, which tends to maintain the speed constant at this value. If the motor is started from rest and the load is not too heavy it will accelerate to half speed, and remain approximately at this speed unless the external torque is less than the value shown by the dotted line *A*. If the torque is less than this value, the motor will continue to accelerate on the upper part of curve *3* and approach full speed. After the motor has reached the upper part of curve *3* it will not again be brought to half speed unless the primary circuit is first opened, thus allowing the motor to drop down below half speed. However, the motor will stop if the load exceeds the dotted line *B*. The value shown by the dotted line *A* depends upon the secondary resistance of the motor and a number of other factors. This arrangement of speed control might be applicable for fans where the torque depends largely upon the speed.

DYNAMIC BRAKING

Direct-current motors are sometimes operated as generators in order to bring the motor to rest. This method of braking is usually referred to as dynamic braking. The field of the motor is excited in a positive manner and the armature is connected in a closed circuit through external resistance. The stored energy of the rotating part of the motor and the load is dissipated as heat in this external resistance. The torque exerted by the motor is equal to the field strength multiplied by the armature current. If a load is being lowered by means of dynamic braking, the speed of the motor can be adjusted by changing either the field strength or the resistance in series with the armature. The latter method is usually employed. Sometimes, as in the case of crane controllers using series motors, a combination of both armature and field control is used, as will be explained later. Where shunt and compound-wound motors are used no special provision needs to be made for energizing the field. A series motor usually has its field connected across the line through a fixed resistance, in order to insure a positive field when using the dynamic brake.

As the braking torque depends upon the voltage generated by the armature, the value of the torque decreases quite rapidly as the motor approaches slow speed and, unless there is considerable friction in the load, it is necessary to provide a mechanical brake for bringing the load to a positive stop. The advantage of the dynamic brake is in reducing the wear and tear on the mechanical brake, as most of the energy of the moving load can be absorbed through dynamic braking, allowing only a small amount of energy to be absorbed by the mechanical brake through friction. The extra work done by the motor during dynamic braking must always be taken into consideration when determining the size of motor that is required for applications where dynamic braking is frequent. Controllers are often provided with a dynamic brake for emergency purposes. Where the motor is stopped infrequently, the heating effect of the dynamic brake need not be considered.

The only practical method of obtaining dynamic braking with induction motors is to supply the primary of the motor with direct current. This gives a stationary field, which produces a voltage in the rotating element of the motor. This voltage will cause a current to flow through a resistance connected to the slip-rings of the motor and thus produce a dynamic braking effect similar to that obtained with a direct-current motor.

This subject is discussed more fully in a separate chapter on the braking of electric motors.

SUMMARY OF CHAPTER XI

Direct-current Motor Speed Control: The speed of d-c. motors may be controlled:

(1) (Varying speed motors) by inserting a resistor in series with the armature to vary the armature voltage. As the drop across the resistor varies with the load the armature voltage and hence the motor speed varies inversely as the load. The motor's inherent change in speed from no load to full load, expressed as a percentage of the no load speed, or by stating the two speeds, is known as its regulation. This change is increased by compounding, or adding series turns to the motor's field. The load of an entirely series-wound motor cannot usually be safely reduced to less than 25 per cent of full load.

(2) By inserting one resistor in series, and a second resistor in shunt, with the armature and varying the two singly or simultaneously.

(3) (Adjustable speed motors) by impressing a constant voltage upon the armature and varying the strength of the field. The maximum field strength or slowest speed is reached when the iron becomes saturated, the minimum field strength or highest speed at the point beyond which the motor becomes unstable. (The method becomes expensive for speed ranges greater than four to one, when the following method is frequently used.)

(4) By maintaining full field and varying a resistor in series with the armature to obtain slow speeds, then impressing constant voltage upon the arma-

ture and weakening the field to obtain the higher speeds. (Practical when the slow speeds are only briefly required or at reduced loads, so that armature resistance losses are small.)

(5) (Variable voltage system) by providing a separate generator for each motor and by varying the field of the generator. To reverse the rotation of the motor the generator field is reversed. Sometimes for higher speeds a two to one adjustable speed motor is used to reduce the size of generator required.

ALTERNATING-CURRENT MOTOR SPEED CONTROL: The speed of a-c. motors may be controlled:

(1) (Varying speed motors) by inserting resistance in the secondary circuit of the motor, so that with increase of load the speed decreases, to compensate for the reduction in secondary voltage due to the increased resistor drop. The maximum torque that the motor is capable of exerting before it "pulls out" and stops is called its pull out torque. The difference between the no-load and full-load speeds expressed as a percentage of the no-load speed is called the motor's slip.

(2) By providing the motor with a high resistance secondary circuit and reducing the voltage on the primary. As the torque varies as the square of the voltage a small reduction in voltage results in a proportionately large reduction in torque, hence this method is seldom used. For the same reason good line voltage regulation is at all times desirable.

(3) By maintaining the primary voltage constant and connecting the slip rings to a source of supply whose voltage and frequency can be varied.

(4) (Adjustable speed motors) by providing two sets of poles in the primary and changing from one set to the other.

(5) By connecting the secondary of one motor to the primary of another equal in cascade, the two motors being mechanically coupled.

(6) By opening a phase of the secondary circuit and operating single phase.

DYNAMIC BRAKING, D-C.: May be obtained by exciting the motor field and short-circuiting the armature through resistance. After the motor is slowed down, unless friction in the load makes it unnecessary, a friction brake is used for making the final stop. In the latter case the dynamic brake greatly reduces wear of the friction brake.

DYNAMIC BRAKING, A-C.: May be obtained by impressing direct current upon the primary and connecting the secondary circuit to a resistor.

CHAPTER XII

MANUAL CONTROLLERS

Drum type of manual controllers—construction and operation—cam type—construction and operation—Dinky face plate type—graphite disc compression type—advantages and limitations of manual controllers.

This chapter will deal particularly with manual controllers of the reversing type which may be used for regulating the speed of the motor as well as starting, stopping, and reversing. A manual controller is one that has all of its basic functions performed by hand. It is the opposite of power operated. The manual controller may be complete in itself or may form only part of the control equipment, such as a master switch. The term controller is a broad designation: when used for accelerating a motor to normal speed in one direction it is usually called a starter. Types of face plate starters are shown in Chapter V.

The drum controller is the best known and at present the most commonly used form of manual controller. When it is used only for reversing a motor, it is known as a drum reverse switch, but generally it has additional points for acceleration and speed control. Types of drum controllers are shown in Figs. 2, 97 and 98. The controller consists of a series of stationary fingers which engage segments on the surface of a cylinder or drum. The cylinder is revolved by a handle and is enclosed in an iron case with a sheet iron cover. The fingers may be mounted in a single row on one side of the drum or in a double row, on opposite sides of the drum.

The drum cylinder usually consists of one or more castings clamped to an insulated square or hexagonal steel shaft; copper straps are attached to the outer surface for engaging the contact fingers, and are sometimes provided with removable arcing tips. In some controllers the drum castings are made of brass or copper and engage the fingers directly without the use of removable contacts, but in most cases the drum is provided with removable contact segments.

The drum shaft has a notched wheel attached either above or below the drum. This is called a star wheel, the notches corresponding to each of the operating positions of the controller handle. Whenever a set of contacts is in its proper position on the drum, a roller is forced into one of the notches on the star wheel by means of a spring. This indicates the exact operating position of the handle for each notch.

The most important item in the design of a drum controller is the contact finger, of which many different types have been made. Each manufacturer has a particular design which he features and which has its advantages and limitations. Fig. 3 shows one type of finger which contains all of the elements usually found in the various designs. There is a contact carrying part which engages with the surface of the drum and is flexibly mounted on a finger base. The pressure between the drum and the finger is maintained by a spring and the current passes from the finger to the terminal through a flexible shunt. The finger base is securely clamped to an insulated iron base and is sometimes provided with an arc shield between it and the drum.

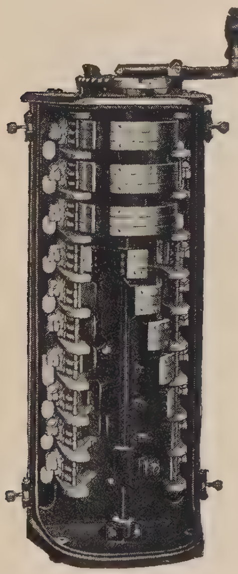

Fig. 97

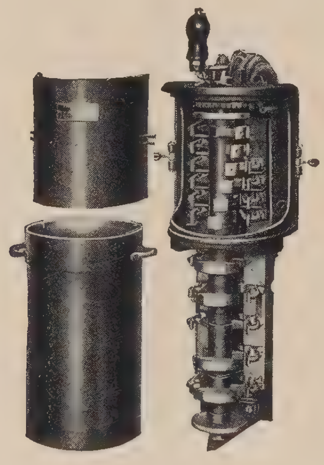

Fig. 98

Fig. 97. Drum Controller, Showing Construction of Fingers and Segments to Handle Heavy Current

Fig. 98. Drum Controller with Primary Contacts Oil Immersed

When the controller is in the off position the fingers are not in contact with the surface of the drum, being opposite the cut away portion of the drum. When the drum is rotated toward the finger base the copper straps on the surface of the drum engage the contact fingers, lifting them and causing them to ride over the copper surfaces. The ends of the fingers are bent outwards so as to strike the straps on the drum obliquely and be lifted by them without stubbing. When the finger and drum are in contact and the drum is rotated away from the finger base the finger being in tension is under little strain, but when first engaged by the drum it is in compression and must be of sufficiently rigid construction to withstand the strain then exerted upon it. When in contact the fingers are lifted through a distance of one-sixteenth of an inch, a stop on the finger permitting it to be adjusted to obtain this condition. Sliding on the drum wears the finger away, so that it must be adjusted from time to time to maintain the proper contact pressure.

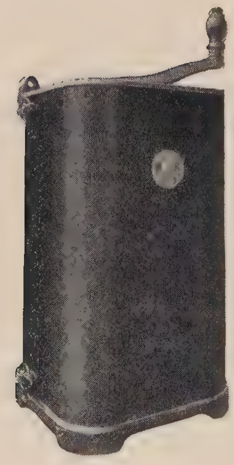

FIG. 99

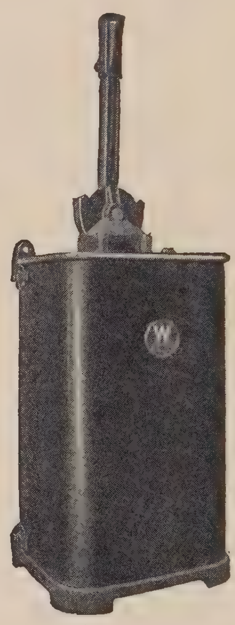

FIG. 100

FIG. 99. Cam Controller with Rotating Handle

FIG. 100. Cam Controller with Lever Handle

When returning the drum to the off position, the contact segment in moving away from the finger forms an arc. This arc is established on one side of the contact surface of the finger and at the edge of the drum segment so that the burning does not take place on the parts ordinarily carrying current. A magnetic blowout is usually supplied with direct current controllers to extinguish this arc. The blowout may consist of a single coil and common magnetic circuit for all of the different fingers, or an individual blowout may be attached to each finger. The latter arrangement gives better results but its extra expense may not be justified except for heavy duty.

The current which a contact finger will carry depends upon the width of the fingers and the pressure between it and the surface of the drum. Tests indicate that if this pressure is in excess of ten pounds per inch of width some form of lubricant should be used or the cutting becomes excessive. The best form of lubricant is a good grade of vaseline spread thinly over the drum segments. Most controllers are designed for contact pressures less than that given above so that the lubricant is not necessary although if the drum is kept clean and lubricated the contact fingers will last longer.

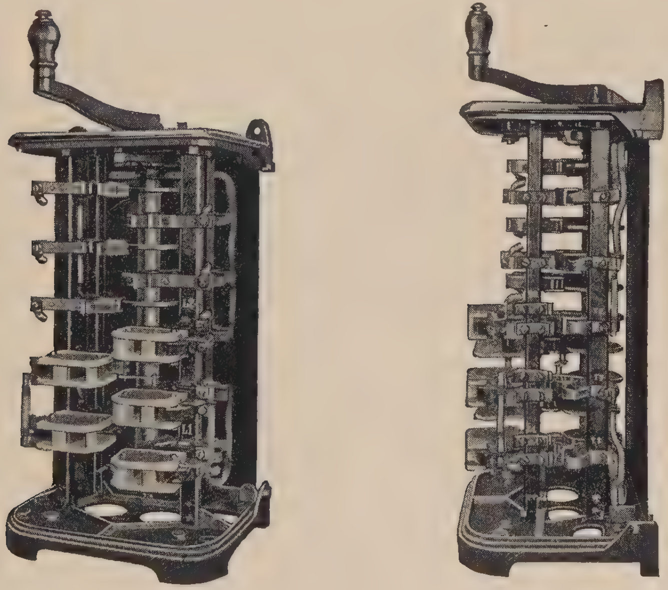

FIG. 101

FIG. 102

FIGS. 101–102. Cam Controllers with Covers Removed

The contactors used in these controllers are shown in detail in Fig. 103. They are mounted on steel bars insulated with micarta tubing

The armature resistor is almost always mounted separate from the drum controller. Where the controller provides for both armature and field control the resistor for the field rheostat may be mounted as part of the controller. The description of controllers of this type will be found in the chapters on Machine Tools. The ordinary reversing controller can be assumed to have a separate armature resistor.

Cam Controllers

Cam controllers have the same general appearance as the drum controllers and are mounted and operated in the same manner, but the contact element is different. In place of the rotating cylinder is a shaft carrying a set of cams, which engage and close a series of contactors which replace the drum fingers. (Figs. 99 to 102.)

The contact mechanism is illustrated in detail in Fig. 103. It consists of a stationary element which may or may not be provided with a blow-out and a movable element held open by a spring and closed by a cam. The action of this contact is exactly the same as that of the magnetic contactor and the same contacts are used.

The illustration shows the three positions of the contact, first, when open; second, when just touching at the tip, and third, when it is entirely closed, making contact at the heel. In opening the process is reversed. This rolling action from the tip to the heel and back again in opening causes the arc to be broken at the tip and the current to be carried at the heel. By using rolling action instead of a sliding action in closing, the mechanical wear is eliminated and much heavier pressures can be used. A more complete discussion of this contact is given in Chapter IV.

The current is carried from the movable contact to the terminal by means of a flexible shunt; one end of the spring is insulated so that no current can pass through this member. On account of the spring being located a considerable distance away from the contact it is not directly affected by the temperature of the contact or the arcing, and is, therefore, in no danger of having its temper drawn due to excessive loads.

The movable contact is attached to a block which in turn is fastened to the hinge member. The surface between this block and the hinge member is corrugated and one of the holes is slotted so that this block can be adjusted to give the proper contact action. After this adjustment is made it should not be necessary to change this block when renewing contacts as all of the contact wear takes place at the tip and does not affect the location of the current carrying parts.

Various combinations of switches can be obtained by changing the number of contactors and the shape of the cams. The length of the frame can be adapted to the desired combination by changing the length of the insulating bars and the sheet iron cover.

Both the drum type and the cam type of controllers can be provided with either a rotating handle or a lever handle. They may also be mounted vertically on the rear of the panel and operated by a hand wheel on the front of the panel through suitable gearing. If the controller is mounted back of the panel with the shaft horizontal, the shaft can be extended directly through the panel without the use of gearing.

Both types of controllers have been built motor operated. The construction is the same as for manual operation, the handle being replaced by a reduction gear and pilot motor.

The drum controller is more compact for certain switching combinations such as reversing. On the other hand, the cam type is more easily designed for complicated switching, and new combinations can be more easily made, as these combinations are accomplished by cutting cams of different shapes, while in the drum design new drum castings are usually required. The cam units can be removed individually without dismantling the controller. The same is true of the contact fingers of the drum controllers; however, the drum shaft must be taken out to replace drum segments, after which it is advisable to true the segments in a lathe before reassembling in the controller. The cam controller has a blowout which compares favorably with that of the magnetic contactor and which is always in the proper direction. Both types when enclosed have a restricted arcing space, and are therefore more limited as to severity of service than magnetic contactor controllers.

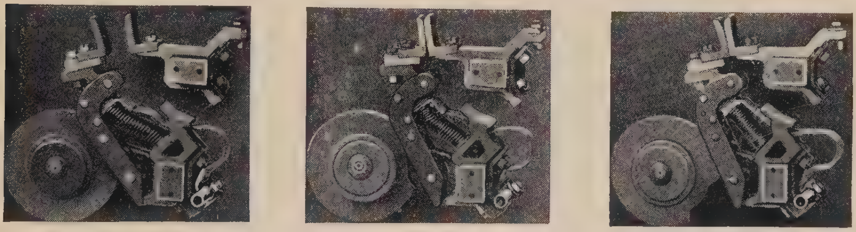

FIG. 103. Details of Contactors Used in Cam Controllers

The contactors may also be clamped to insulated plates instead of bars. These contacts are of the rolling type—note the action during closing. The contact is established at the tips and rapidly transferred to the heel or lower portion of the contacts during the closing process. This process takes place by a rolling action. When opening, the process is reversed, throwing all of the arcing at the tip of the contact

FACE PLATE CONTROLLERS

One of the most popular forms of manual controllers in steel mill service is known as the Dinky controller (Figs. 104 and 105). It somewhat resembles the ordinary face plate rheostat although it is much more rugged in construction. A series of stationary contacts are mounted on an insulated base, and a pair of brushes making contact with these rotate around a central shaft. The brushes make contact between an outer and inner row of contacts. The handle usually projects from the top of the controller and actuates the brush arms by means of a pinion and gear segment so that a relatively small motion of the handle is multiplied into a large motion of the brushes. The stationary contacts are made removable from the face of the controller without disturbing the electrical connection. The brushes can also be renewed when necessary.

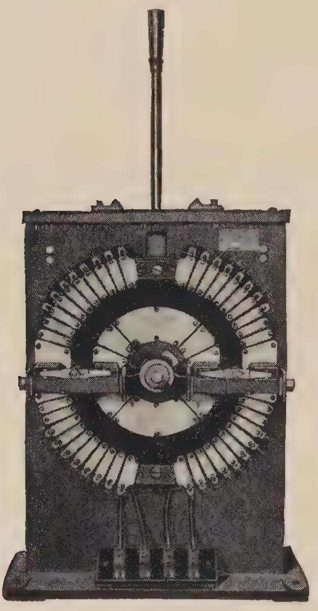

FIG. 104. Dinky Type Plain Reversing Controller

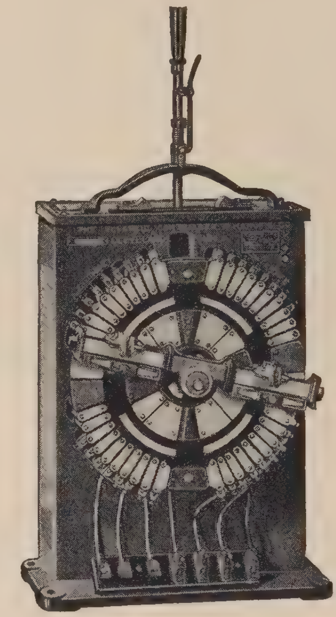

FIG. 105. Dinky Type Dynamic Braking Controller

The resistor is mounted in the controller frame back of the face plate, the whole forming a self contained unit.

A modification of this type of controller is known as the grindstone type, illustrated in Figs. 8 and 9. The contacts of this controller are mounted around the periphery of an insulated base, in the semblance of a grindstone, to which fact it owes its name.

COMPRESSION TYPE CONTROLLERS

Compression type controllers (Figs. 106 to 108) differ from all other types of controllers. Instead of a number of contact segments connected to taps on the resistor, several columns of graphite discs are used,

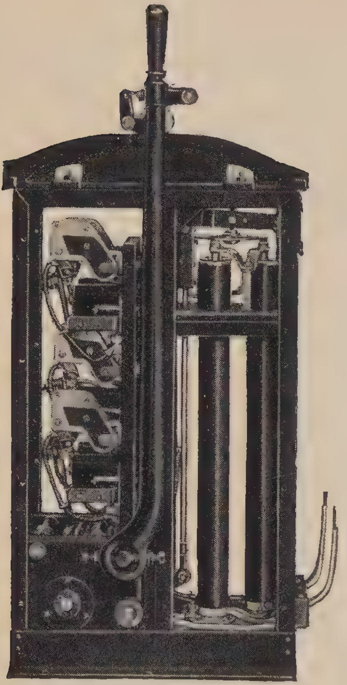

FIG. 106

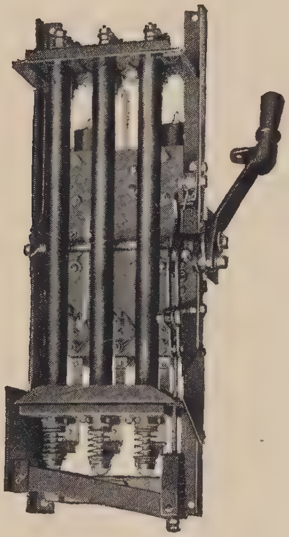

FIG. 107

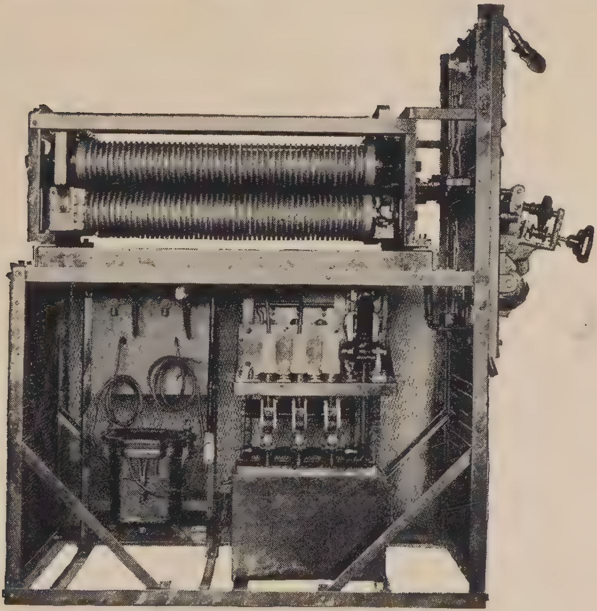

FIG. 108

FIGS. 106–107–108. Mill and Crane Controllers of the Graphite Compression Type the change in resistance being obtained by varying the pressure between the discs. This form of resistor is shown in greater detail in Figs. 168 and 169.

The illustration shows the face plate type of contact, but other forms of this controller have been made using contactors.

Comparison of Types

The latter two controllers described have the resistor self-contained with the switching mechanism, whereas the first two usually have separately mounted resistors. The drum and cam types may have either a rotating or a lever handle, but the other two types are always provided with lever handles. The four are representative of many that are now being successfully used. Other forms of controllers are built and doubtless from time to time improvements will arise, but in the present state of the art the types described show the principles used in all manual controllers.

Manual Controllers versus Magnetic Contactor Controllers

The advantages and limitations of manual controllers depend to a large degree upon their size and application requirements. The following list of advantages and limitations should be interpreted broadly as there are many applications for manual controllers which would not justify the use of contactor control.

The advantages of a manual controller as compared with a magnetic contactor controller are:

(1) The first cost is less.

(2) The space occupied by the controller is usually less and the weight is less. In some applications the weight and space requirements are often a determining factor.

(3) Simplicity. Manual controllers usually have no electric interlocks so that the wiring connections can be easily followed.

(4) These controllers are readily enclosed to protect them against dust, dirt, and moisture. The drum and cam controllers are often made water tight for use on shipboard.

Limitations:

(1) The larger sizes of manual controllers require more effort to operate, and may, therefore, tire the operator if frequent use is necessary.

(2) The contacts will wear more rapidly, as their operation is not as positive. The quicker the contacts are opened and closed, the less the maintenance cost.

(3) The arcing takes place near the operator. This is not objectionable in

small controllers, but it is safer to have the main arc rupturing parts located remote from the operator where a considerable amount of power is being handled.

(4) The larger size manual controllers occupy more space than the master switch of the magnetic type and on cranes and some other applications, therefore, a large manual controller may interfere with the operator's seeing his work.

(5) A separate protective panel is required for manual controllers to obtain overload and low voltage protection, required in many applications. In some water tight controllers it has been found necessary to mount the protective panel in the same case as the master controller.

VENTILATING REQUIREMENTS

In rupturing the arc, ionized gases are produced which must be removed by ventilation. Where the manual controller is enclosed the air space surrounding the arc rupturing parts is limited and the ventilation poor. Where the circuit is opened and closed frequently, trouble may result from the accumulation of these gases. This difficulty does not arise with small controllers. and may be avoided in the larger type by ventilating the enclosing cover. (These limitations may also occur in the magnetic type of controller where the enclosure is restricted.) This condition is sometimes overlooked so that a properly designed controller has been discredited, whereas improper application was the cause.

Whatever type or design of controller is used, provision must be made for disposing of these ionized gases. The more quickly the arc is ruptured the less gas will be produced. When an enclosed controller is used the arcing heats up the air space within the enclosure and limits the current carrying capacity of the contacts and other parts. The more frequent the arcing, the greater the heating. This is a limitation sometimes overlooked.

Manual controllers are usually rated either for intermittent duty or for continuous duty. Continuous service presupposes only a small amount of arc rupturing. Intermittent service must assume a certain amount of heat to be generated by the arc. The more frequently the circuit is opened the less time the current carrying parts will be in circuit, and the increase in air temperature inside the enclosure due to arcing, therefore, will be counterbalanced by a smaller amount of energy lost in heating the current carrying parts. Conditions may arise, however, under which the current is left on longer than intended or the current is ruptured more frequently than was estimated when the controller was rated. Engineering skill, therefore, is required in selecting a controller, to determine if any unusual conditions of this kind exist in a particular application.

SUMMARY OF CHAPTER XII

Manual Controllers:

Manual controllers are designed for hand operation, but in the drum or cam types the operating wheel or lever may be replaced by a gearing and motor for pilot motor operation. They may start, stop, control the speed, or reverse the rotation of a motor. A starter starts and stops a motor in one direction only. A drum reverse switch is a drum type controller that starts, stops, and changes the direction of rotation.

Drum Type: In the drum controller copper segments mounted on a cylinder or drum complete circuits by making contact, when the cylinder is rotated, with stationary fingers. The finger is specially designed to prevent stubbing when it strikes the copper segment. For heavy currents a magnetic blowout is added. When a finger pressure greater than ten pounds per inch of width is necessary the segments are lubricated (vaseline recommended as best).

Cam Type: In the cam controller, cams on a revolved shaft close in sequence contactor mechanisms like those of magnetic contactors. Blowouts may be added.

For some applications, as for reversing, the drum type is more compact. The cam type is more easily adapted to complicated combinations, it being only necessary to cut new cams, while for drum controllers new castings are required.

Dinky Type: Contacts are mounted circularly on a vertical flat base, and engaged by diametrical contact arms which are turned by means of a shaft and gearing by moving the operating handle.

Grindstone Type: Similar to the Dinky type except that the contacts are mounted on the periphery of an insulated base, as on the surface of a grindstone.

Compression Type: Similar to the face plate type except that resistors in the form of columns of graphite discs are used, the resistance being varied by compressing the discs.

Manual Versus Magnetic Controllers: Advantages of manual controllers over magnetic controllers:

(1) low first cost;
(2) compactness;
(3) simplicity (interlocks are eliminated);
(4) ease of protection against dust and moisture.

Limitations of manual controllers as compared with magnetic controllers:

(1) they require more effort to operate;

(2) the contacts wear faster;

(3) the arc is broken near the operator (objectionable when switching heavy currents);

(4) they occupy more space than the master switch used with magnetic contactors (objectionable when space available for master switch is limited, as in cranes);

(5) they require a protective panel to obtain overload and low voltage protection; and, the arcing space being restricted,

(6) they require skilled judgment in applying, and greater precautions against heating.

CHAPTER XIII

DIRECT CURRENT MAGNETIC CONTACTOR CONTROLLERS

Direct current magnetic contactor controllers, non-reversing type—reversing type—use of field rheostat—controller defined—types of master switches used—low voltage release—low voltage protection—overload protection—applications.

Magnetic contactor controllers may be divided broadly into non-reversing and reversing controllers. Where several contactors are used for short-circuiting sections of the resistor in the armature circuit, the connections to the operating coils of these contactors can be made in succession by means of a drum-type master switch. The motor can in this case be operated with more or less armature resistance, depending upon the number of contactors whose circuits are closed through the master switch. The number of resistance steps can be altered to suit the application. The writer believes that one step of resistance is sufficient for starting direct-current motors up to 15 horse-power, 230 volts, where the starting duty is light, and that two steps may be used for heavy starting. If it is desirable to regulate the speed of the motor, additional steps should be provided. The acceleration of the motor quite frequently is automatic, even when several running points are provided.

Non-reversing Controllers

Non-reversing controllers are usually connected on one side of the motor circuit only and consist of a line contactor, a resistor and one or more contactors for short-circuiting the resistor. A two-pole knife switch is usually required with this type of controller, the knife switch being connected so that it will disconnect both sides of the motor and controller from the line. The line contactor may be provided with a bottom contact for short-circuiting the armature of the motor through a fixed resistance to give dynamic braking when the line switch is opened. A diagram and an illustration of a controller arranged for dynamic braking are shown in Figs. 109 and 110.

In some cases it is desirable to open both sides of the motor circuit when the controller is in the *off* position. This can be done by providing two line contactors. This arrangement, however, is not usually employed, as it adds to the expense, and opening the knife switch by hand accomplishes the same result. The knife switch is needed so that the contactors can be disconnected from the line to renew the contacts or make adjustments.

Reversing Controllers

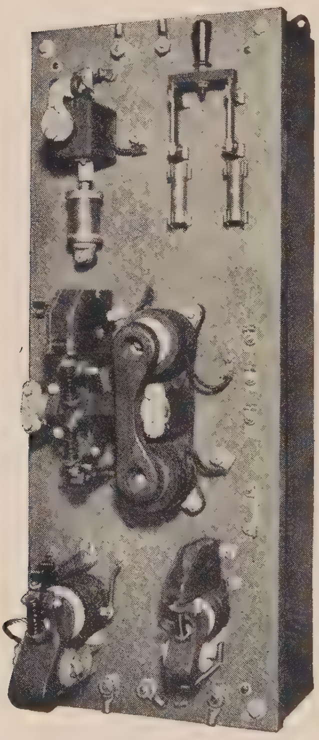

Fig. 109. Typical Non-reversing Automatic Controller
Arranged for dynamic braking

In order to reverse the armature of a direct-current motor it is necessary to disconnect both sides of the armature from the line. This necessitates the use of four single-pole contactors or two double-pole contactors, two contacts being closed for either direction of operation. It is the usual practice to arrange either a mechanical or an electrical interlock between these contactors, so that the forward and reverse contactors can not both be closed at the same time, as this would result in a short-circuit and might injure the apparatus. The resistor in series with the armature is short-circuited in steps by magnetic contactors in the same manner as for non-reversing controllers. Frequently the resistor is connected directly to one side of the motor, so that the line contactors in their *off* position disconnect the armature entirely from the line, as shown in Fig. 111. Since both sides of the motor circuit are opened by contactors, the shunt field cannot be connected so it will discharge through the armature of the motor.[1] It is therefore good practice to provide the shunt field with a parallel resistance to take up the inductive discharge when the field circuit is opened. If this resistance is omitted, a high voltage is generated in the field windings, which may ultimately result in puncturing the insulation.

The reversing controller can be arranged for dynamic braking by providing a bottom contact on one of the forward and one of the reverse direction switches, so connected that when both of these switches are open the armature will be short-circuited through a resistor, as shown in Fig. 112.

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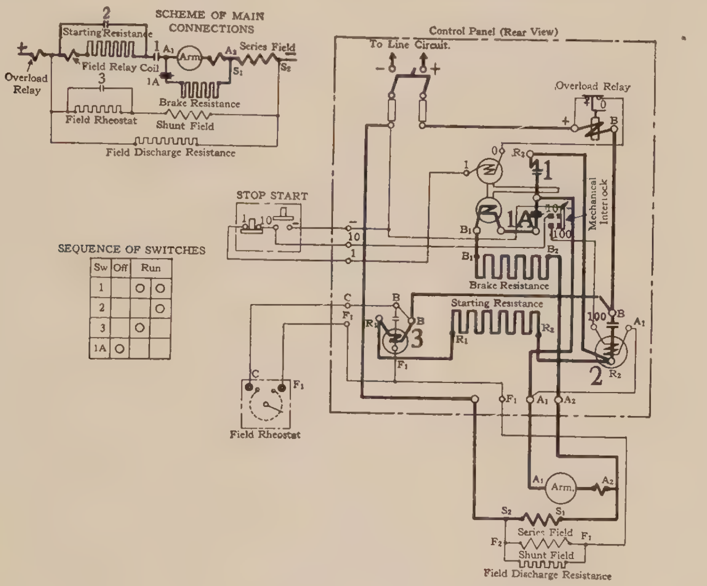
[1] As explained in Chapter V.

FIELD RHEOSTATS

Where a controller is used with an adjustable speed motor, a field rheostat is used for changing the resistance of the field circuit to adjust the speed of the motor. This field rheostat may be mounted on the controller panel or separate from it. It is considered better practice to mount this rheostat separate from the control panel, so that the operator will not be required to place his hand close to the magnetic contactors when



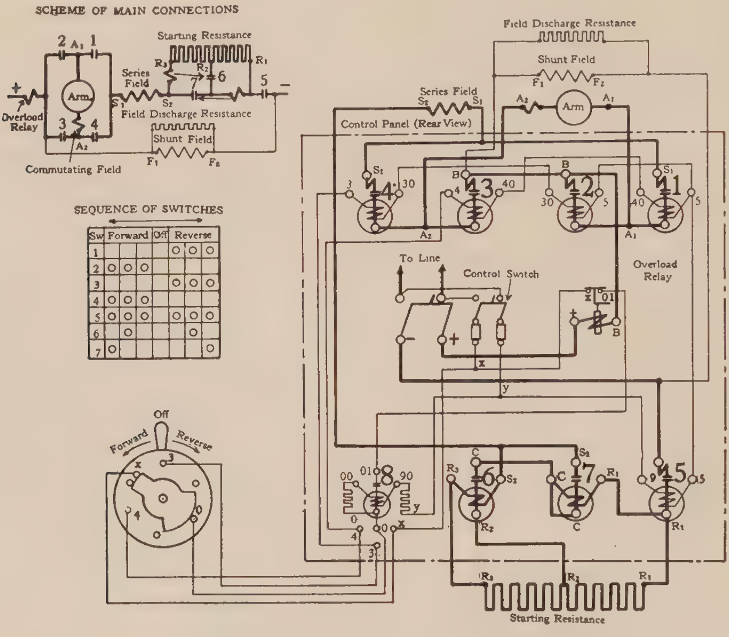
SEQUENCE OF SWITCHES

Sw	Off	Run	
1		○	○
2			○
3		○	
1A	○		

FIG. 110. Diagram of Panel Shown in Fig. 109

Pushing the *start* button results in closing line switch *1*, which closes the mechanical interlock contacts and opens the bottom contacts at *1A*. The motor then starts, with the starting resistance in series. Switch *3* simultaneously short-circuits the field rheostat, ensuring full field as long as the starting resistance is in series with the armature. When the counter e.m.f. of the accelerating armature reaches a predetermined value, switch *2* closes and shunts the starting resistance out of the circuit. Short-circuiting this starting resistance causes switch *3* to open, so that field control is possible by the use of the field rheostat, after the motor comes up to speed. The dynamic braking resistance is connected across the armature terminals whenever switch *1* is open. Series operating coils on *1A* prevent the motor from being started while the heavy dynamic braking circuit is flowing, and also ensure good contact pressure.

they are in operation. The separately mounted field rheostat can be covered to prevent the operator from coming in contact with any live parts. Usually the contactor panel is quite large and must be mounted in a more or less inaccessible place. The field rheostat, however, is small and can be located close to the master switch. Sometimes the master switch and field rheostat are combined in one unit.



SEQUENCE OF SWITCHES

Sw	Forward			Off	Reverse		
1					○	○	○
2	○	○	○				
3					○	○	○
4	○	○	○				
5	○	○	○		○	○	○
6		○				○	
7	○						○

FIG. 111. Double-pole, Reversing, Automatic Controller

The master switch makes contact between *o* and *x* in the *off* position between *o* and *4* in the *forward* position; and between *o* and *3* in the *reverse* position. Switch *8* provides overload and low-voltage protection. Its operating coil is connected directly across *xy* through the master controller in the *off* position, and (by an interlock underneath coil *8* connecting *o* and *x*) across *xy* through the overload relay in the running positions. This means that in case the motor is stopped for any reason, it is impossible for it to be restarted until the master controller has been turned to the *off* position. Switches *6* and *7* are of the magnetic lock-out type, and cannot close until after the current flowing on their control coils drops below a predetermined value.

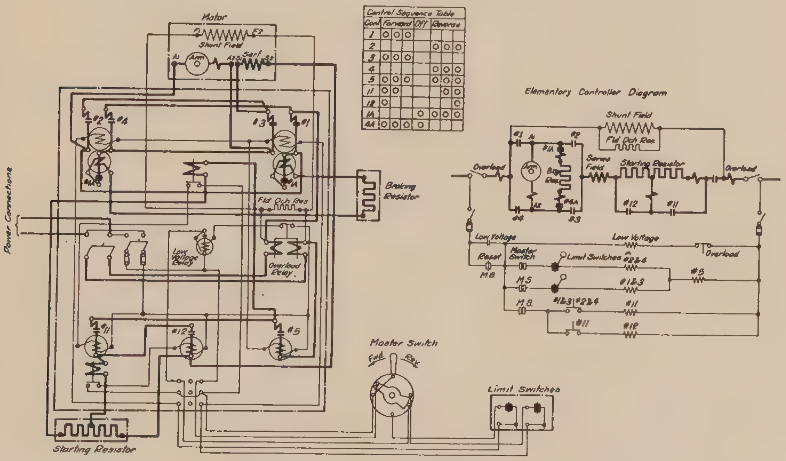
CONTROLLER SUMMARY

To sum up: A controller is made up of a magnetic contactor panel, either reversing or non-reversing, with or without dynamic brake. Some form of master switch is provided to operate the controller, and a field rheostat may be added. This gives the essential elements for the control of an electric motor.

MASTER SWITCHES

The master switch is an auxiliary switch which serves to govern the operation of contactors and auxiliary devices of electric controllers. It usually takes the form of a push button, float switch, pressure switch, thermostat or drum switch. Other forms, of course, are in use, and any device which opens and closes the circuit may be used as a master switch.

The push button switch is the most common and is perhaps used more than all of the other types combined. An ordinary start and stop push button is shown in Fig. 114. More elaborate combinations of push buttons are used for printing presses, electric elevators, and other applications where a complicated sequence of operation is required.



Control Sequence Table							
Cont.	Forward			Off	Reverse		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○	○		○	○	○
11	○	○				○	○
12	○						○
1A				○	○	○	○
4A	○	○	○	○			

FIG. 112. Double-pole, Reversing, Automatic Controller, Arranged for Dynamic Braking from Either Direction of Rotation

Switches *1* and *3*, as well as *2* and *4*, are mechanically connected and controlled by the same operating coil, thus forming a double-pole contactor. Dynamic braking is accomplished, as in Fig. 110, by bottom contacts *1A* and *2A*

A float switch is shown in Fig. 116 and a pressure switch in Fig. 117. These switches are used in connection with pumps and similar installations. The float switch, as its name implies, consists of a hollow metal box used as a float, which opens and closes the master switch for different levels of the liquid in which it is placed. The pressure switch has a diaphragm which opens the contacts at the maximum pressure and closes them at the minimum pressure for which it is adjusted. Various forms of thermostats are used in connection with refrigerating machinery for starting and stopping the motor-driven machinery at different temperatures.

A drum-type master switch is shown in Fig. 115. This is usually in the form of a small drum controller and may be operated by the rotation of a handle or with a forward and back motion of a lever. Under this class should be included also switches in which the contacts are arranged on a face plate instead of a drum, and where the contacts are operated by cams. The drum type of master switch is usually applied where the sequence of operation is more or less complicated; also where frequent operation is required.

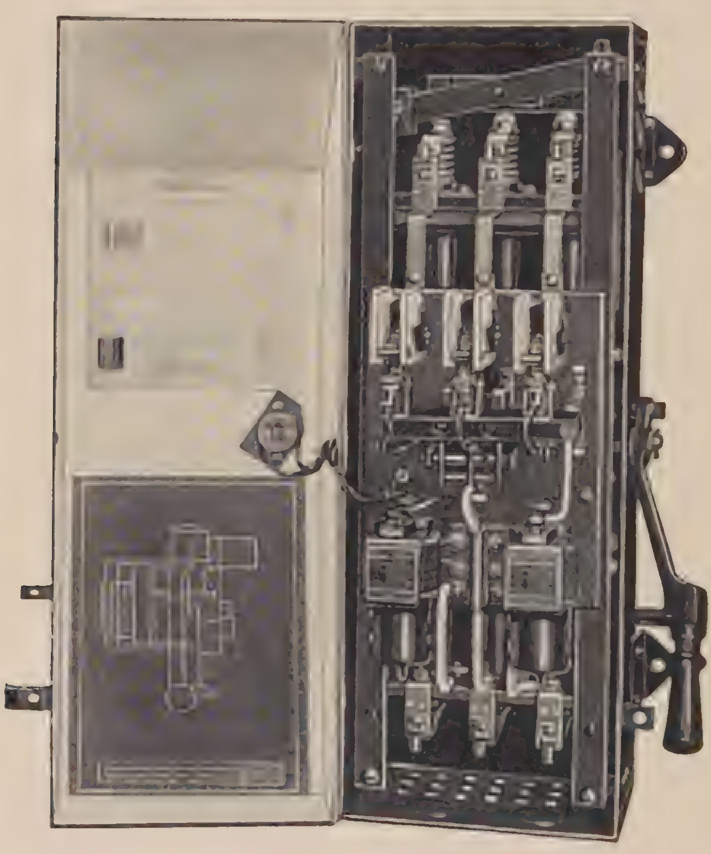


FIG. 113. Semi-automatic Starter of the Type Graphite Disc Compression

Most master switches may be connected to either reversing or nonreversing controllers. There are two general methods employed, one of which is known as low-voltage release and the other as low-voltage protection. The Electric Power Club defines these two methods of voltage protection as follows:

Low Voltage Release.—The effect of a device operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not preventing the re-establishment of the main circuit on return of voltage.

Low-Voltage Protection.—The effect of a device operative on the reduction or failure of voltage to cause and maintain the interruption of power to the main circuit.

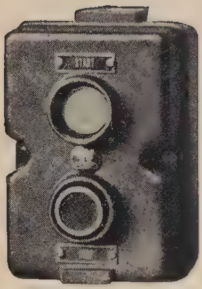


FIG. 114. Pushbutton Station

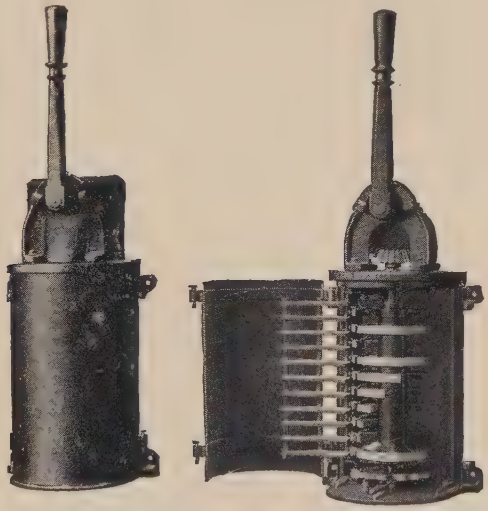


FIG. 115. Six-point Drum-type Master Controller

The reason for making the above distinction is largely a matter of safety. If the motor drives a woodworking machine, for instance, the machine may be at rest due to the absence of line voltage. Under these circumstances, the operator might be engaged in adjusting the machinery, or for some other reason have his hands close to the cutting tools. If the line voltage is restored at such a time, the operator might easily be injured. This applies to a variety of machinery. Gears are a source of danger from this cause. These gears are usually protected under operating conditions, but this protection might be removed when the machine is at rest. In order to guard against accident from this cause, the master switch is so connected to the controller as to afford low-voltage protection. This requires the operator to perform a manual operation on the master switch in order to start the motor after it has once come to rest due to a failure of voltage.

Where the motor operates a fan or pump, it is very desirable to have the apparatus start automatically after a failure of voltage. In such cases there is little or no danger due to the automatic starting of the motor, and a great deal of inconvenience and possible danger might result from the failure of the motor to start when the voltage is restored to the line. The master switch under such conditions is connected to give low-voltage release. This arrangement automatically starts the motor again, when the line voltage is restored.[2]

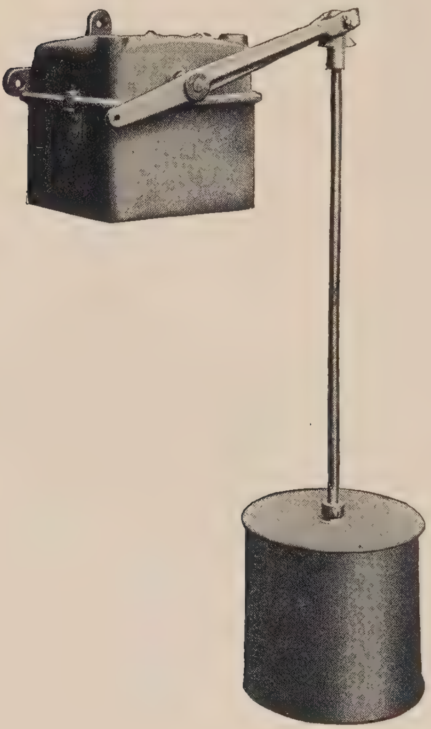


FIG. 116. Enclosed-type Float Switch

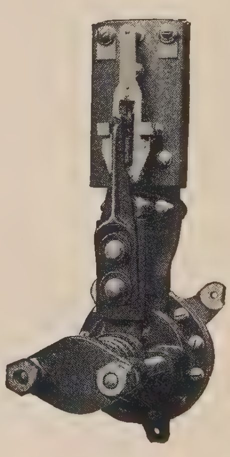


FIG. 117. Diaphragm Pressure Regulator

OVERLOAD PROTECTION

It is usually necessary to provide some form of overload protection in connection with the controller. The most common form of protection is the fuse, usually of the cartridge type. These fuses have a certain amount of time element and therefore are well adapted for control apparatus. In starting a motor or during its operation, heavy currents may be taken by the motor for a few seconds. These do not injure the motor or controller, and therefore it is desirable to have a time element in the overload device. This occurs to a limited extent when a standard enclosed fuse is used.

Another common form of overload protection is a series relay which opens a contact by means of a magnet when the current exceeds a certain value. These relays are often furnished without a dashpot, and therefore their action is instantaneous. It is much better practice to use a dashpot to obtain a time element, so that the relay can be given a setting more nearly equal to the full-load current of the motor. Where a magnetic contactor is used on only one side of the line, a single-pole relay may be used with this contactor, but it is necessary to use a fuse on the other side of the line. The advantage of a relay is that it can be restored to its normal position very easily. The fuse, however, must be replaced by a new one. If a combined relay and fuse is used, it is usual to select a fuse with a higher rating than the setting of the relay, so that under ordinary conditions of overload the relay will operate and save the fuse.

It takes some time to raise the temperature of a motor to a dangerous point when it is overloaded. If this overload is within the commutating limits of a motor, the additional load will not injure the motor until the temperature has been raised to the danger point. This usually takes from five minutes up to a half-hour or more, depending upon the size of the motor and the amount of overload. If the overload is continued indefinitely it will injure the motor, but short periods of operation are permissible. The result has been that operators set the overload protection high enough so as not to operate on short-time peak loads. Therefore, the motor is without any real protection against continuous overloads. Very few fuses, overload relays, circuit breakers or similar apparatus give complete protection to industrial motors. They operate in case of short-

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[2] Fig. 43 shows a pushbutton master switch connected to a controller to afford low-voltage protection. If a float-type master switch were connected between the terminals *1* and —, the same controller would give low-voltage release. By providing three terminals for the master switch of such a controller, it can be connected for either low-voltage release or protection. Many standard diagrams show both methods of connection.

circuits or abnormal overloads, but usually they are set too high to open on a small overload, which may be sufficient to injure the motor if continued for a long time. There is, therefore, opportunity for developing time-element overload devices which will have time elements of five to thirty minutes instead of five to thirty seconds, as is the case with most of the existing apparatus. The longer the time element can be made, the more desirable it is for operation of motors.

It is often stated that an overload relay having a long-time element will not operate quickly enough in case of a short-circuit or a ground to protect the motor. Standard practice, however, requires the use of fuses or a circuit breaker at the point where the motor circuit leaves the main power wires. The fuses or circuit breaker at this point must be set to protect the wires leading to the motor. If these wires are made a little larger than for the full-load capacity of the motor, the circuit breaker at this branch point may be set so that it will not operate on normal overloads of the motor, but will protect the motor under abnormal conditions, and also afford protection to the wires leading to the controller. The ideal protection, therefore, is feeder protection against short-circuit and a time-element overload device on the controller to protect the motor against continuous overloads, but which will permit overloads for short periods of time.

Overload relays are commonly made up in three forms:

1. To allow the armature to return to the open position immediately after the overload has been removed. The function of such a relay is to open the line contactor. Connections are made so that the contactor will be retained in the open position until the master switch is manipulated.

2. The overload relay is provided with a catch which holds the armature in the closed position and requires the energizing of a separate magnet to release the catch and restore the relay to its normal condition.

3. This is the same as *2*, except that the catch is released by hand instead of by a magnet. This is objectionable because the operator must place his hand on the device, which is in the neighborhood of live parts.

Arrangement *1* is the more common and is usually preferred, owing to its simplicity and cheapness. Arrangement *2* is usually connected to the master switch, so that the relay is reset by moving the master switch to the center or *off* position.

APPLICATIONS

The magnetic contactor controllers described above are those having the most general application. A few of the typical applications are for motors driving line shafting, pumps, machine tools, woodworking machinery and, in fact, any apparatus that is motor driven that does not require a special arrangement of circuits.

SUMMARY OF CHAPTER XIII

When it is necessary to open the field circuit of a direct current motor, and there is no other path to take care of the discharge, a parallel (field discharge) resistor should be connected to the field at the moment of opening, to avoid puncture of the insulation by the high voltage generated.

An automatic or magnetic controller consists of a master switch, a magnetic contactor panel, arranged for reversing or nonreversing service, with or without dynamic braking, and sometimes a field rheostat. The master switch (push button, float switch, pressure switch, or drum switch) opens and closes circuits to the panel contactors or other operating devices. In the case of failure of voltage, after return of voltage to the line it may permit the motor to resume operation (low voltage release), or prevent it (low voltage protection).

A fuse or relay, operating in from five to thirty seconds, may protect against overload. As overload devices are frequently set too high, to avoid interruption of service on short time overloads that do not injure the motor, there is an opportunity for developing a longer time element device (five to thirty minutes) that will not operate on short overloads but will protect the motor if the overload becomes too prolonged. An overload device after operating permits the motor, if low voltage release is used, to resume operation automatically (automatic reset); if low voltage protection is provided, when a hand or electrically operated latch is released (hand or electrical reset).

CHAPTER XIV

ADJUSTABLE SPEED A-C. MOTORS OF THE WOUND ROTOR TYPE

Adjustable speed sets, d-c. analogy—constant torque type—constant horsepower type—adjustable speed sets, a-c.—how changing secondary voltage adjusts speed—Method I (secondary a-c., through rotary converter, drives d-c. motor coupled to main shaft: constant horsepower)—Method II (secondary a-c. returned to line through rotary converter and d-c. motor-induction generator set: constant torque)—Method III (secondary a-c. returned to line through polyphase commutator motor-induction generator set; constant torque)—Method IV (secondary a-c. drives polyphase commutator machine coupled to main shaft: constant horsepower)—Method V (secondary a-c., through frequency changer, drives synchronous machine coupled to main shaft: constant horsepower)—Method VI (secondary a-c. returned to line through self-driving frequency changer: constant torque).

The wound rotor induction motor can have its speed adjusted by connecting the secondary circuit to an external source of power having suitable characteristics. The principle of operation may be illustrated by referring to a similar scheme using direct-current machines. If we assume a d-c. motor *A*, Fig. 118, having a d-c. machine *B* in series with its armature and assume that this d-c. machine is operated at a constant speed by another d-c. machine, *C*, it can be readily seen that by changing the voltage of this regulating machine *B*, the speed of the main motor *A* can be adjusted. Assuming that *B* runs at constant speed and that its field is capable of adjustment over a wide range and that it is provided with interpoles so that it will operate successfully at zero field strength, we can then obtain a voltage from *B* which either opposes the flow of current through the motor *A* or assists that current. In other words, the machine *B* interposes an active voltage in the armature circuit of machine *A*. This voltage may oppose the line voltage, reducing the speed of *A* below normal or it may add to the line voltage, increasing the speed of *A* above normal voltage. If we wish to reduce the speed of motor *A* fifty per cent, the machine *B* would have half the capacity of *A*. When the motor *A* is operating below normal speed, the difference in power represented by this difference in speed is absorbed by the machine *B* which acts as a motor driving the machine *C* as a generator and returning this power to the line.

If the motor *A* is operated above normal speed, power is taken from machine *B* which then becomes the generator and machine *C* a motor receiving current from the line. The torque of machine *A* remains constant throughout the speed range as this torque is fixed by the field strength which is assumed constant and the current carrying capacity of the armature. Therefore, this equipment operates at a constant torque throughout its range, the horse-power varying with the speed. (These statements and those that follow are all based on the assumption that the equipment is operating at its rated full load current.)

If we couple the machine *B* to the main motor *A* as shown in Fig. 119, the speed of *A* can be adjusted in a similar manner to that shown in Fig. 118, by varying the field strength of machine *B*. In this case the difference between the operating speed and the normal speed of the main motor *A* is absorbed by machine *B* and converted into mechanical work. The torque of *A* remains constant but the torque of *B* will change with the change of speed, the resultant torque of the equipment being inversely proportional to the speed and the horse-power remaining constant.

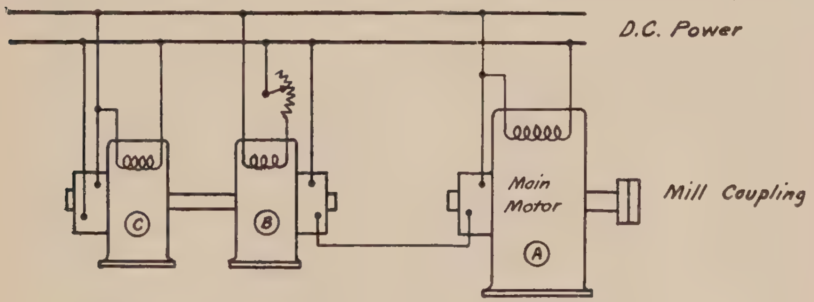

FIG. 118. D-C. Adjustable Speed Set, Constant Torque

If we consider the schemes shown in Fig. 118 and Fig. 119, we will note that the main current passes through machines *A* and *B* in series. If we assume that this current is always equal to full load current and that the supply voltage is constant, it will be seen that the power supplied to this circuit has a constant value. In Fig. 119 there are no other connections to the line and, therefore, if the losses are kept small this scheme should deliver a constant horse-power corresponding to the constant power input. The arrangement in Fig. 118, however, provides an additional circuit through machine *C*. There is a constant power input to machines *A* and *B* to which the power input of machine *C* should be either added or subtracted depending on whether machine *A* is running above or below normal speed. The total power received from the line is, therefore, a function of the speed. The torque, however, is obtained from one machine only, namely the main motor *A*. Therefore, this equipment delivers a constant torque as compared with the constant horse-power delivered by the equipment in Fig. 119.

If we keep these two schemes in mind and consider the a-c. motor, we will find that the methods used for controlling this motor are either constant torque or constant horse-power and that they function in a similar manner to the d-c. motor.

The line voltage connected to the primary of an induction motor must be balanced by a counter voltage set up in the windings due to the alteration of the flux through these windings. This counter voltage is a little less than the line voltage, the difference being consumed by the ohmic and leakage reactance drops caused by the load current. Assuming that the line voltage, the frequency and the load on the motor remain constant the primary flux remains constant. Most of this flux also passes through the secondary. If the secondary revolves at synchronous speed, its conductors do not cut this flux and there is no secondary voltage or current, therefore, no work is done by the motor. In practice, the secondary revolves at a little less than synchronous speed. This difference in speed generates a secondary voltage which causes the secondary load current to circulate, which in turn requires a corresponding increase in the primary current in the ratio of transformation. The difference between synchronous speed and actual speed is commonly called the slip of the motor. Let us assume that this slip amounts to three per cent of the synchronous speed of the motor. The motor, therefore, operates at ninety-seven per cent of synchronous speed at full load. If we now connect the secondary circuit to a source of power of the same frequency, we can impress an external voltage upon the secondary

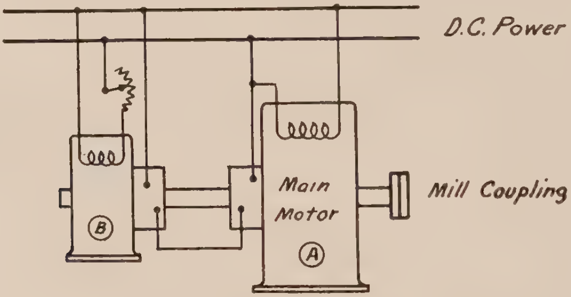

FIG. 119. D-C. Adjustable Speed Set Constant HP.

windings. If this impressed voltage has the proper phase relation the secondary will revolve at a less speed as more slip will be required to generate the additional voltage made necessary by that supplied from the external source. This can be more easily understood by referring to Fig. 120. We will let the line *AB* represent the amount and direction of voltage required in the secondary to circulate the load currents and the line *CD* the voltage supplied from the external source. We must then generate in the secondary circuit a voltage *EF* which is opposite to the two previous voltages and equal to their sum. In order to generate this voltage the secondary must run at a less speed. The motor can be operated above synchronism by changing the direction of the voltage supplied from the external source. Fig. 121 shows a similar analysis. The line *AB* represents the value and direction of voltage required to circulate the load current. This is the same as in Fig. 120. The line *CD* now represents the value and direction of the voltage supplied from the external source. The secondary of the motor must, therefore, develop a voltage having a value and direction corresponding to *EF*. As this voltage is in the opposite direction to that in Fig. 120, it is necessary for the motor to operate above synchronism.

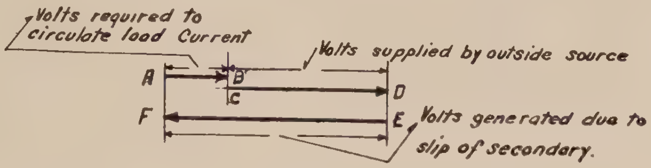
Volts required to circulate load Current
Volts supplied by outside source
A
B
C
D
F
E
Volts generated due to slip of secondary.

FIG. 120. Secondary Voltage Distribution, Motor Operating Below Synchronism

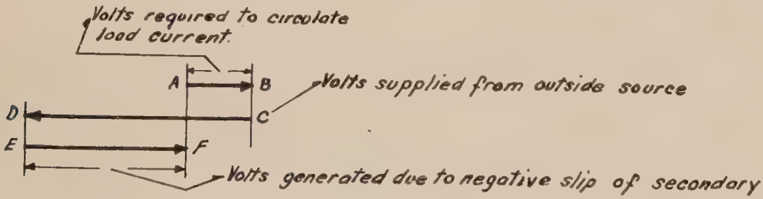
Volts required to circulate load current
A
B
Volts supplied from outside source
D
C
E
F
Volts generated due to negative slip of secondary

FIG. 121. Secondary Voltage Distribution, Motor Operating Above Synchronism

Figs. 120 and 121 show that when the motor is operating below synchronism, the voltage required to circulate the load current is obtained by a decrease in speed and, therefore, by less work being delivered by the motor. When operated above synchronism, this voltage is supplied as part of the power obtained from the external source. In both cases the voltage required to circulate the load current represents a loss; in one case the loss appears as less mechanical work, while in the other case the loss is made up from a source of power external to the motor itself.

The performance of the a-c. machine is similar to that of the d-c. machines previously described with the additional limitation that in the a-c. machine we must take into consideration the power factor and frequency of the circuits in the secondary of the motor in addition to the voltage. In the d-c. machine we are only concerned with voltages. In both a-c. and d-c. machines the speed of the motor can be adjusted either above or below normal speed by changing the voltage impressed upon part of the motor windings from an external source.

Several different methods have been used for introducing the variable voltage in the secondary circuit of a wound rotor motor. Some of these methods also include means for changing the power factor so that the normal power factor of the motor may be improved or even changed to a leading power factor. In all of these methods the main motor is started from rest by connecting the secondary through a resistor with means for short-circuiting this resistor as is done with standard equipments. Diagrams, Figs. 122 and 123, show this resistance, together with a change-over switch for connecting the motor to the adjustable control after it has come up to speed. This method of starting has been omitted from all except Figs. 122 and 123 for the purpose of simplicity as the means of starting has nothing to do with the principle of speed adjustment.

In describing the following methods no attempt will be made to develop the theory or to furnish vector diagrams illustrating the phase relation between the different voltages and currents. A very complete analysis of these problems is given in the A.I.E.E. proceedings.[1]

Method I. This method consists of a main driving motor coupled to a d-c. machine. The secondary of the main motor is connected to the slip rings of a rotary converter. The direct-current side of the rotary converter is connected to the armature of the d-c. machine. The fields of the rotary and d-c. machine are excited from a constant voltage source of direct-current. Diagrammatically this scheme is illustrated in Fig. 122.

In starting from rest the secondary of the main motor *A* is connected to a resistor which is gradually short-circuited by means of magnetic contactors in the usual manner. After the main motor has been brought up to speed, its secondary is transferred to the rotary converter.

The voltage on the d-c. side of the rotary is changed by varying the field of the d-c. machine *B*. This changes the voltage impressed on the secondary motor *A*, which changes the speed of this motor. At the same time the change in voltage on the rotary changes the speed of the rotary. These two actions take place simultaneously. The a-c. side of the rotary is connected to the secondary of the main motor *A*. Therefore, the frequency in the two machines remains the same and the change in speed takes place simultaneously.

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[1] Transactions of the A.I.E.E., Vol. XXXIX, Part II (July to Dec., 1920), page 1135 ff.

To reduce the speed of the main motor, the field of the d-c. machine *B* is increased. This causes an increased voltage to be applied to the secondary of the main motor through the rotary converter which in turn reduces the load current or may momentarily reverse this current. The main motor will then slow down until the sum of the generated voltage and the supplied voltage in its secondary is enough less than the ratio of transformation to cause full load current to flow through the secondary. The reduction in speed in turn reduces the voltage of the d-c. machine so that a balance running speed is soon reached. The speed is increased by reducing the strength of the d-c. motor field. The power represented by the difference between full speed and actual speed is converted into work through the rotary converter and the d-c. machine causing this machine to give a torque which adds to or subtracts from the torque of the main motor *A*. If the set is running at seventy-five per cent of normal speed, the main motor will be delivering seventy-five per cent of its rated output and twenty-five per cent will be delivered by the d-c. machine. The torque of the main motor remains constant as this is fixed by the excitation of the primary and the design characteristics of the machine, both of which remain constant. The direct-current motor, however, increases its torque as the speed of the main motor decreases. When

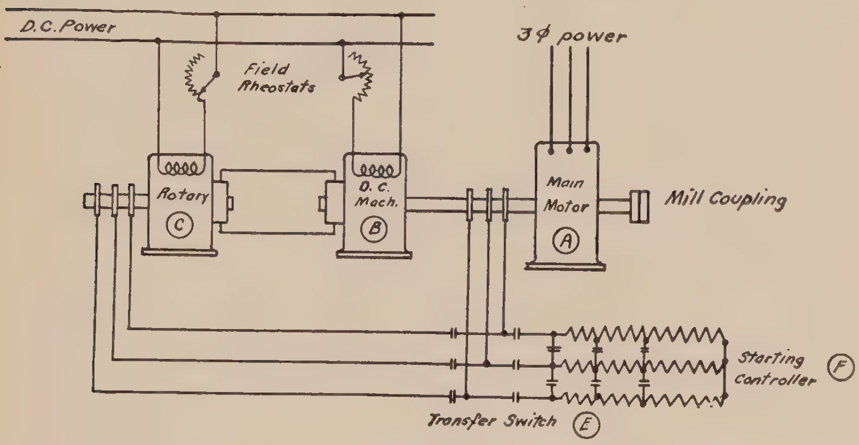

FIG. 122. Diagram Showing Method I, Constant HP.

the main motor *A* is operated above synchronous speed the torque of the d-c. machine *B* is subtracted from the torque of *A*. The torque delivered by the d-c. machine is directly proportional to the change in speed of the main motor so that the horse-power output of the combined unit remains practically constant.

The power factor of the main motor can be altered by changing the excitation of the rotary fields. In this way the power factor of the motor may be increased so that it is above ninety per cent but ordinarily a leading power factor is not obtained.

This method can be used to operate the main motor above synchronism as well as below synchronism. If operation at normal speed is desired, the regulating set can be disconnected and the secondary of the main motor short-circuited.

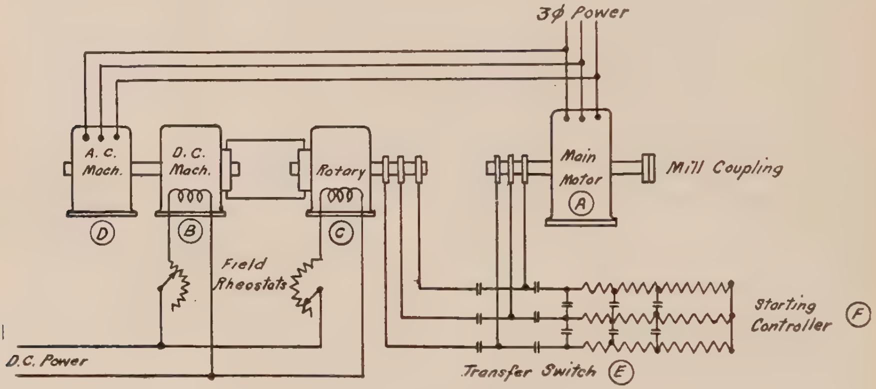

FIG. 123. Diagram Showing Method II, Constant Torque

METHOD II. This method is similar to Method I except that for the d-c. machine coupled to the main motor a motor generator set not coupled is substituted. The scheme of connections is shown in Fig. 123. The operation is very similar. The rotary converter *C* supplies power to the d-c. machine *B* which drives the a-c. machine *D* and returns power to the line. The speed of the main motor is adjusted by changing the field strength of the d-c. machine *B*. The difference between these two schemes is that in the first method power is converted into mechanical work and returned to the main motor shaft. This gives a constant horse-power throughout the range of the equipment. In Method II, power is returned to the line. The main motor operates at constant torque but the horse-power decreases with the speed. The power returned to the line is the difference between the horse-power which the motor would deliver at full speed and the horse-power which it actually delivers at the reduced speed. In both methods the losses are very small and most of this difference in power is saved. By reversing the polarity of the power supplied to the secondary of the a-c. motor it may be made to operate above synchronism. This may be accomplished in several ways; the additional power in this case will be taken from the line by the motor generator set.

METHOD III. This equipment, Fig. 124, consists of a main driving motor, *A*, having mounted on its shaft a small frequency changer *D*. Separate from this main motor is a set consisting of an a-c. induction or synchronous machine *C* coupled to an a-c. commutator machine, *B*. The a-c. commutator machine *B* is operated at nearly constant speed by the a-c. machine *C* to which it is coupled. The field strength of this commutator machine is varied in order to supply different voltages to the secondary of the main motor. The method of varying this field consists in connecting one end of each field coil to an auto-transformer, in the secondary of the main motor. The other end of each field coil is connected through a resistance to the low frequency or commutator end of the frequency changer *D* mounted on the main motor shaft. The frequency changer is so connected that when the main motor is operated at synchronous speed, the commutator end of the frequency changer supplies

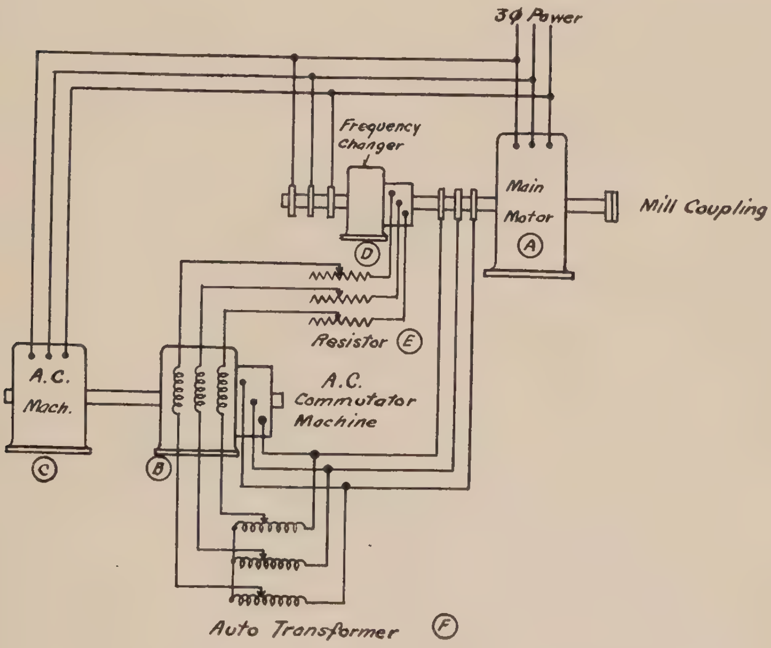

FIG. 124. Diagram Showing Method III, Constant Torque

direct current. At any other speed of the main motor an alternating-current is supplied to the field which has the same frequency as the secondary of the main motor. This can be better understood by referring to Fig. 125. When the main motor is operating below synchronism, we can let the line *AB* represent the frequency due to the rotation of the a-c. field and the line *BC* the frequency due to the rotation of the frequency changer armature which is coupled to the main machine *A* and rotates at the same speed as that machine. The line *CD* will then represent the difference in these frequencies and will be the frequency which is delivered at the commutator end of the frequency changer. Since this frequency is equal to the difference between synchronous speed and the actual speed of the main motor it will be the same as the frequency in the secondary of the main motor for all speeds of the main motor.

Since the field of the commutating machine *B* is excited by two sources of power out of phase with each other and independently adjustable (phase relation of the frequency changer by shifting the brushes; current from the frequency changer by varying the resistor; and voltage from the auxiliary commutator circuit by adjusting the autotransformer), both the phase relation and strength of the excitation can be controlled. This adjusts the phase and amount of voltage impressed on the slip rings of the main motor *A*, and provides a ready means for adjusting its speed and power factor. Motor *A* may be operated at a leading power factor when desired.

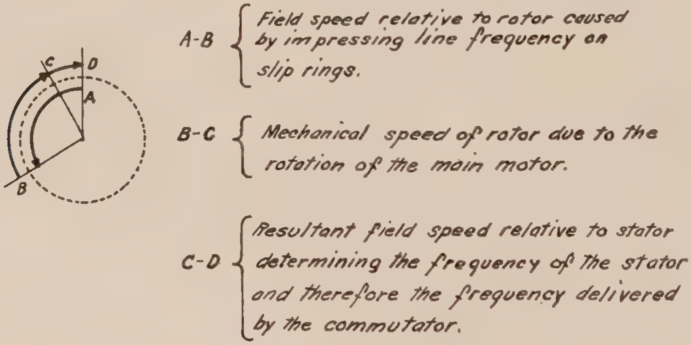
C
D
A
B
A-B { Field speed relative to rotor caused by impressing line frequency on slip rings.
B-C { Mechanical speed of rotor due to the rotation of the main motor.
C-D { Resultant field speed relative to stator determining the frequency of the stator and therefore the frequency delivered by the commutator.

FIG. 125. Analysis of Frequencies in Frequency Changer

The speed of the main motor can be adjusted from below synchronism to above synchronism while operating under load. In order to pass through synchronism the voltage impressed upon the secondary of the main motor must equal zero when the main motor is operating at about three per cent below synchronous speed in order that there will be sufficient voltage to circulate the load current. When the main motor reaches synchronous speed the frequency of the secondary circuit is zero and the voltage from the autotransformer *F* is zero, therefore, the commutating machine *B* is excited entirely from the frequency changer *D* on the main motor shaft; the voltage supplied from machine *B* must now be sufficient to circulate the load current. This voltage is in the opposite direction to that impressed on the secondary below synchronism. The transition can be illustrated by Figs. 120 and 121. As the motor approaches synchronous speed (Fig. 120) the line *BC* is reduced in length until it reaches zero. The line *EF* then equals *AB* and the voltage of machine *B* is zero. In order to obtain a further increase in speed the voltage supplied by machine *B* is reversed, and the line *EF* reduces, to zero and then reverses as shown in Fig. 121.

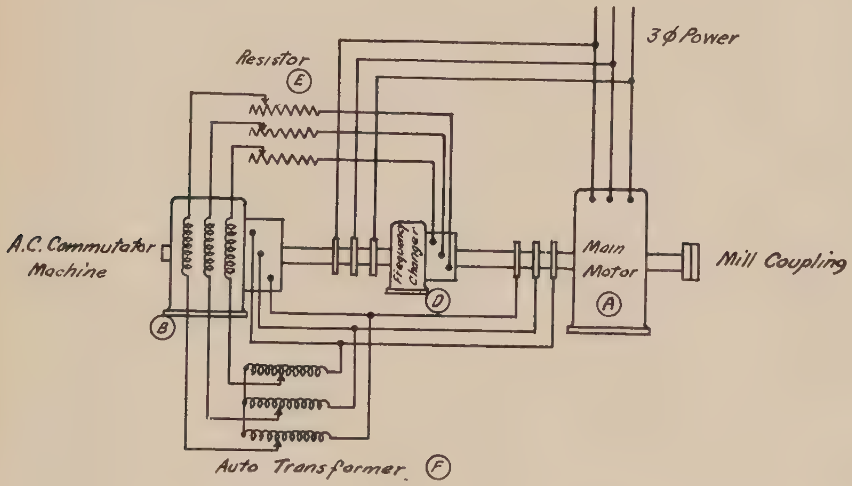

FIG. 126. Diagram Showing Method IV, Constant HP.

The torque of the main motor remains constant throughout the range and the horse-power varies directly with the speed. The difference in horsepower represented by a speed slower than synchronism is returned to the line through the commutator machine and the induction machine which it drives. When operating above synchronism, the extra power is obtained from the line through the synchronous or induction machine to the commutator machine and then to the main motor. The power input to the primary and the torque of the main motor remains the same for all speeds, the horse-power varying with the speed.

METHOD IV. This method is the same as Method III except that the commutator machine *B* is coupled to the main motor shaft instead of being driven by a separate a-c. machine. The scheme is illustrated diagrammatically in Fig. 126. The energy represented by the difference in speed is converted into work by the a-c. commutator machine *B* which either adds to or subtracts from the torque of the main motor *A* depending on whether the set is operating below or above synchronism. The equipment, therefore, operates on a constant horse-power basis, no energy being returned to the line.

METHOD V. -The main driving motor *A* has a synchronous machine *B* coupled to the same shaft. Mounted separate is a frequency changer *C* driven by a small synchronous motor. The diagram of connections is shown in Fig. 127. The secondary of the main motor is connected to the commutator end of the frequency changer. The slip ring side of the frequency changer is connected to the synchronous machine on the main motor shaft. The d-c. field of this synchronous machine *B* can be varied by means of the field rheostat.

The frequency changer runs at a constant speed corresponding to the synchronous speed of the line. The synchronous machine coupled to the main motor operates at a speed greater or less than synchronism, corresponding to the slip of the main motor. If we represent the slip of the main motor by *S* then the frequency of the synchronous machine is equal to one plus or minus *S*. This frequency is imposed upon the slip ring side of the frequency changer which in turn delivers a frequency equal to the slip in the secondary of the main motor on account of the frequency changer operating at synchronous speed. This arrangement insures that the frequency of power supplied to the main motor is of the correct value.

The voltage delivered by the synchronous machine coupled to the main motor is adjusted by changing the strength of the d-c. field. This voltage is transmitted through the frequency changer to the secondary of the main motor which rotates at the proper speed to develop a voltage sufficiently above or below that supplied by the frequency changer to circulate the load current (Figs. 120 and 121). By adjusting the value and direction of the voltage of the synchronous machine the main motor may be operated either above or below synchronism at any speed within the range of the equipment.

The power factor of the main motor may be adjusted either by shifting the brushes on the commutator end of the frequency changer or by shifting the poles in the synchronous motor *D* driving this machine. This motor is very small compared with the frequency changer as it only has to overcome the friction and windage losses, therefore, the poles can be shifted economically by winding the field coils in sections and connecting them to a small rheostat.

The power taken from the supply lines remains constant. The difference in power delivered by the main motor due to a reduction in speed is converted into mechanical energy by the synchronous machine coupled to the motor shaft. In this way a constant horse-power is delivered to the mill coupling at all speeds.

Method VI. This method (Fig. 128) uses a frequency changer having a wound stator and a rotor with a commutator on one end and slip rings on the other end. The commutator end is connected to the slip rings of the main motor and the slip ring end to the line through an autotransformer. The speed of rotation of the frequency changer is controlled by changing the resistance in the stator winding. Its performance is similar to a wound rotor induction motor, the slip rings supplying energy to the rotor which in this case is the primary member, the stator being the secondary. The amount of slip or speed is fixed by the resistance in the secondary circuit.

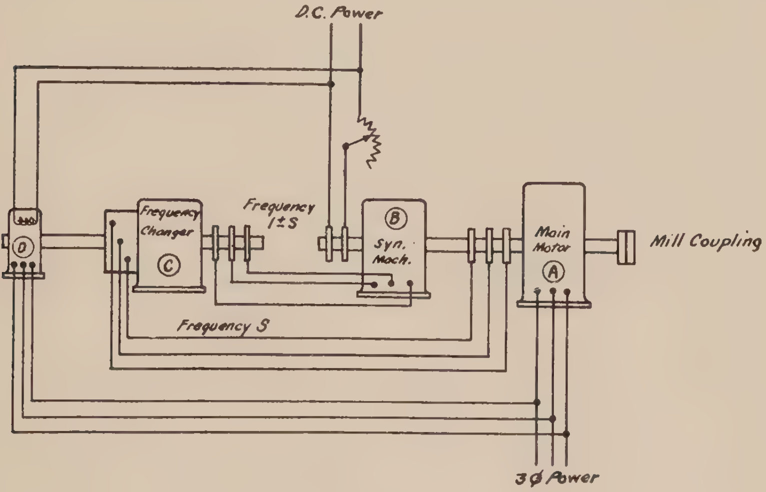

Fig. 127. Diagram Showing Method V, Constant HP.

Another method would be to excite the stator from the commutator end of the frequency changer and change the speed by a resistance in this circuit.

The voltage supplied to the secondary of the main motor depends upon the voltage imposed on the slip rings of the frequency changer by the autotransformer *B*, at the same time the speed at which the frequency changer operates must be adjusted to maintain its secondary frequency the same as that of the main motor secondary. When operating above synchronism, energy is taken from the line.

A modification of this method consists in coupling the frequency changer *C* to the shaft of the motor *A* and omitting the stator windings. The frequency changer in this case operates exactly the same way as the machine *D* in Fig. 124, Method III, with the exception that in Method III, this machine furnishes power to the fields of the a-c. commutator machine *B*, while in Fig. 12 the frequency changer *C* would supply the power directly to the secondary of the main motor *A*. In the latter case the frequency changer must be large enough to supply the power represented by the difference in speed required either above or below normal speed of the main motor *A*. The speed is fixed by that of the main motor *A* which is usually quite slow so that the frequency changer might be quite large and expensive. The arrangement, however, is very simple and can be easily operated through synchronism, stable operation being obtained at all speeds.

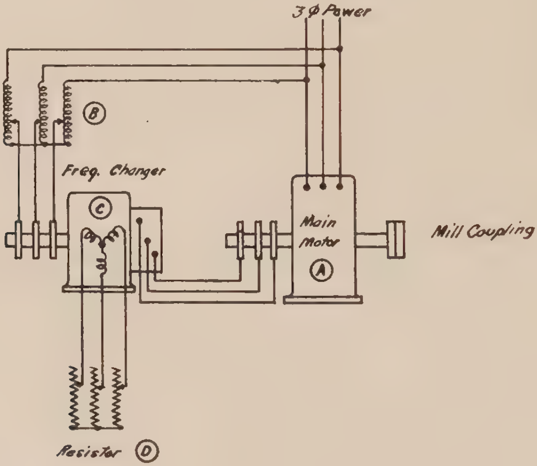

FIG. 128. Diagram Showing Method VI, Constant Torque

These methods of control of wound rotor induction motors were first developed for large motors, used for driving the main rolls in steel mills. There are two general methods of rolling steel. One consists in passing the metal back and forth through one set of rolls, the other method uses a number of sets of rolls, the metal passing continuously from one set to the next. This latter is known as a continuous mill. Where a single stand of rolls is used, two rolls only may be employed, the motion of the metal back and forth being obtained by reversing these rolls. When this method of rolling steel is used the driving motor must be reversed quickly and frequently, therefore, direct-current motors are used with the voltage method of control described in Chapter XX.

If three rolls are used and the metal passes one way between the bottom pair and then back between the upper pair, the rotation is continuous in this direction and the alternating-current motor can be used. The speed of this motor may be adjusted by any one of the methods described above. In most cases the speed is adjusted for a particular class of work and is not changed between passes. The speed is adjusted when rolling begins and remains fixed until the class of work is changed. In most cases it is not necessary to adjust the speed under load which simplifies the controller. The three high mill is illustrated in Fig. 335. (See chapter on steel mill floor controllers.)

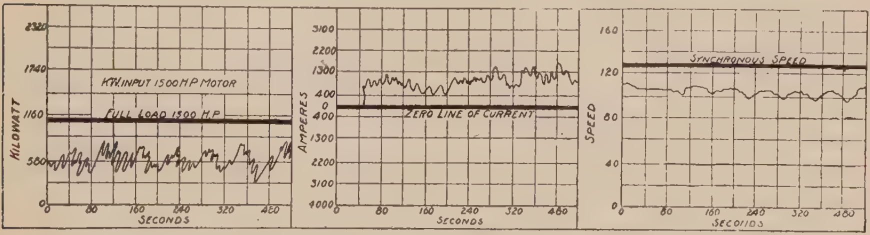

FIG. 129. Characteristic Curves of 1500-hp., Constant-horsepower, Adjustable-speed Set

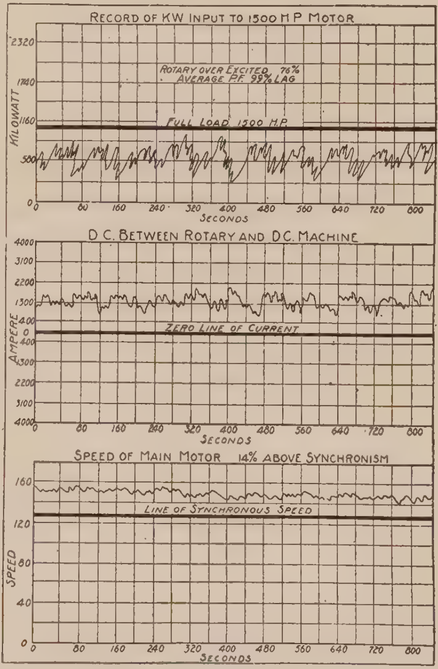

FIG. 130. Characteristic Curves of 1500-hp. Constant-horsepower, Adjustable-speed Set Operating 14 Per Cent Above Synchronism

When the continuous process of rolling steel is used, the roughing rolls or those through which the steel is passed first are often driven at a constant speed by an a-c. motor and only the finishing rolls are provided with adjustable speed a-c. motors.

The speed regulation of a-c. motors between no load and full load can be made very close, the difference being due to the voltage required to circulate the load current. In some cases the load varies over a considerable range and it is desirable to provide a fly wheel to absorb the peak load. In order to have this fly wheel effective it is necessary for the motor to drop in speed when the load comes on. This result can be obtained either by increasing the resistance in the path of the load current or else by designing the regulating machine to have the proper characteristics to give this result. The curves shown in Figs. 129 and 130 show the speed variations of one of these adjustable sets operating below and above synchronism.

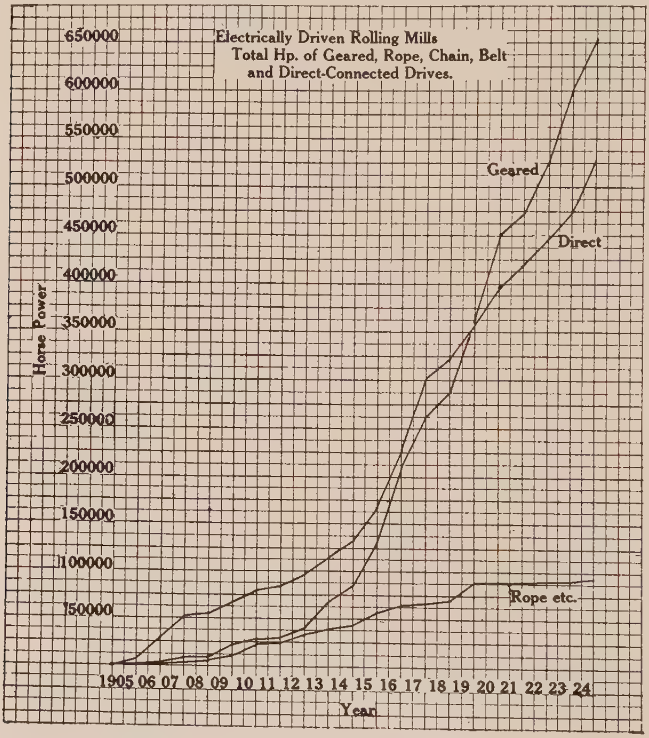

FIG. 131. Curve Showing Increasing Use of Rolling Mill Motors

Electric motors have now almost entirely replaced steam engines for rolling steel where new equipments are installed. The curves (Fig. 131) show this increase in total horse-power over a period of several years. The efficiency and flexibility of the electric drive has made an entire change in engineering practice. The slow speed reciprocating engine has been supplanted by the high speed turbine. Steam as a prime mover is used now almost exclusively for the development of electrical energy which in turn is applied to the work by means of the motor. The application to steel mills is only one illustration of this change.

SUMMARY OF CHAPTER XIV

ADJUSTABLE SPEED SETS, D-C. ANALOGY

The principles of a-c. adjustable speed sets may be understood by referring to similar schemes using d-c. machines, for example:

(1) CONSTANT TORQUE TYPE: The armature of a separately driven generator is connected in series with the main motor armature, to increase or reduce the voltage on the latter, accordingly raising or lowering the speed. At speeds above normal the separate motor generator set takes power from the line and supplies it to the main motor, at speeds below normal it absorbs power from the main motor and returns it to the line. The horsepower varies directly as the speed and the torque remains constant.

(2) CONSTANT HORSEPOWER TYPE: A d-c. machine is coupled to the main motor shaft, its field supplied from the line and its armature connected in series with the main motor armature, tending to accelerate or retard the main motor according as its field is varied. At speeds above or below normal its torque is accordingly subtracted from or added to the torque of the main motor, hence the torque of the set varies inversely as the speed and the horsepower remains constant.

ADJUSTABLE SPEED SETS, A-C.

HOW CHANGING SECONDARY VOLTAGE ADJUSTS SPEED: The rotor must revolve at a speed sufficiently lower than synchronous speed to generate enough voltage to circulate the load current through the secondary windings. If an opposing voltage of the proper frequency and phase relation is introduced into the secondary circuit, the rotor must now generate sufficient additional voltage to overcome the opposing voltage and hence revolves at a still lower speed. On the other hand, if the voltage introduced assists the generated voltage the speed of the rotor may be raised above synchronism. With a suitable transforming medium the power taken from the secondary may be restored to the line (here the horsepower varies as the speed and the torque remains constant) or returned to the main shaft (the torque then varies inversely as the speed and the horsepower remains constant).

Six methods may be noted, as follows:

METHOD I: The secondary a-c. is changed into d-c., through a rotary converter, the d-c. into mechanical power, through a d-c. auxiliary machine coupled to the main motor, and returned to the main shaft (constant horsepower). The speed is adjusted by varying the field of the d-c. auxiliary machine.

METHOD II: The secondary a-c. is changed into d-c., through a rotary converter, the d-c. into a-c. of primary voltage and frequency, through an auxiliary set consisting of a d-c. motor and an induction generator, and returned to the line (constant torque). The speed is adjusted by varying the field of the d-c. motor.

METHOD III: The secondary a-c. is changed into a-c. of primary voltage and frequency, through an auxiliary set consisting of a polyphase commutator machine and an induction machine, and returned to the line. An exciting transformer and a frequency changer exciter, coupled to the main motor, are used to excite the commutator machine. (Constant torque.) The speed is adjusted by varying the field of the polyphase commutator machine.

METHOD IV: The secondary a-c. is changed into mechanical power, through a polyphase commutator machine coupled to the main motor, and returned to the main shaft. An exciting transformer and a coupled frequency changer exciter are used. (Constant horsepower.) The speed is adjusted by varying the field of the polyphase commutator machine.

Method V: The secondary a-c. is changed, through a frequency changer driven by a synchronous motor, to a-c. of different voltage and frequency, and this (impressed on the stator of a synchronous machine coupled to the main motor) to mechanical power and returned to the main shaft (constant horsepower). The speed is adjusted by varying the field of the synchronous machine.

Method VI: The secondary a-c. is changed, by a self-driving frequency changer auxiliary, into a-c. of primary frequency and returned to the line (through an autotransformer or through an auxiliary set of two synchronous machines) (constant torque). The speed is adjusted by varying a resistor in the stator circuit of the frequency changer.

CHAPTER XV

ALTERNATING-CURRENT CONTROLLERS

Wound secondary induction motor controllers—unbalanced method of short-circuiting starting resistance—liquid controllers—squirrel-cage induction motor controllers—autotransformer starter—analysis of current distribution in an autotransformer.

MANY types of alternating-current motors have been built and a variety of methods of control have been devised. However, very few alternating-current motors, other than induction motors, are used in industrial work, and the methods of control in common use are quite simple.

WOUND SECONDARY MOTORS

When resistors are used for accelerating or controlling the speed of induction motors they are usually placed in series with the three-phase wound secondary of the motor. The ends of this winding are brought out to three slip rings on the motor shaft, so that resistance may be inserted between each of the three rings.[1] The method of control corresponds very closely to that of a compound-wound motor with only a small amount of series field. In studying this type of control and applying it, the problem is simplified if the operating conditions are considered to be those of the corresponding direct-current motor and no attempt is made to analyze the complicated reactions that are taking place in the wound secondary motor.

This method of control requires the use of a primary switch, which should be separated electrically from the part of the control which is used for changing the resistance of the secondary circuit. Usually the secondary is wound for less than 600 volts, and in standard motors the secondary voltage and current do not change materially for different primary voltages. This fact makes possible the use of the same secondary controller with a number of different primary switches. For a primary potential of 600 volts or less, air-break switches are used. If it is 2200 volts or more, oil switches are frequently employed, although for certain classes of service air-break magnetic contactors have come into use.

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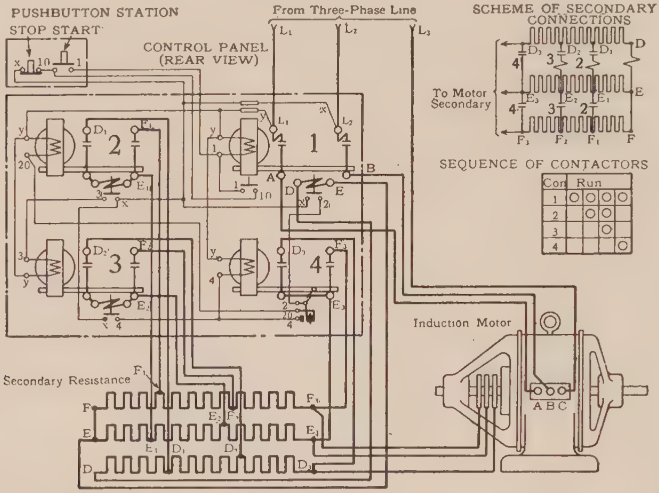
[1] The operation of a motor controlled in this way is explained in Chapter XI, Fig. 93.

Where the motor operates in one direction only, the primary switch often consists of a circuit breaker or a knife switch and fuses, and either a face place or drum-type secondary controller is used. If automatic acceleration is required, both the primary and secondary control consist of magnetic contactors, as shown in Fig. 132.



Con	Run			
1	○	○	○	○
2		○	○	
3			○	
4				○

FIG. 132. Diagram of Automatic Controller for a Three-phase Induction Motor

Contacts *1—10* are held open mechanically when switch *1* is open, and closed when switch *1* is closed. Contacts *x—2* are held open by a spring when switch *1* is open, and the spring pressure is released when switch *1* closes. These contacts are still held open magnetically, however, until the current in the coil *DE* drops below a predetermined value. Contacts *x—3* and *x—4* are similarly interlocked to switches *2* and *3*, respectively. The interlock at the bottom of switch *4* is thrown to the right when the switch is open, and to the left when the switch is closed.

Pushing the start button causes line switch *1* to close, and this switch is held closed through contacts *1—10* after the start button is released. Switch *2* is closed through circuit *x-2-20-y* as soon as the current in coil *DE* drops below a predetermined value. Switches *3* and *4* are similarly closed automatically when the current in D_1E_1 and D_2E_2 drops below the predetermined value. The interlock below switch *4* interrupts the control circuits to switches *2* and *3*, allowing them to drop open, and holds switch *4* closed independently of the interlocks of switches *2* and *3*. Pushing the stop button interrupts the control circuit of switch *1*, causing it to open; and this action opens contacts *x—2*, allowing switch *4* to open.

If the motor is to be reversed at frequent intervals, a drum controller having both primary and secondary switches is generally used for small motors.[2] Large motors usually require magnetic contactors, in which case the same master switches and the same method of overload protection may be employed as for direct-current control.[3] Low-voltage release or low-voltage protection can be obtained in the same way.

There are several methods for arranging the resistors in the secondary circuit of wound rotor motors. In each case sections of resistance are short-circuited by contactors. One method consists of short-circuiting these sections simultaneously on all three legs of the circuit. This keeps the resistance balanced and is theoretically the best method to employ. It requires the use of two contactors or their equivalent for each step of control.

A more economical method consists in short-circuiting the resistor in one leg of the circuit at a time. This requires the use of only one contactor per step and uses the control equipment to much better advantage. Theoretically the unbalancing resulting from this method of control is objectionable. A careful analysis of this problem shows that when the unbalancing is properly arranged that the performance of the motor is not materially changed from balanced operation and a number of other advantages are secured.[4]

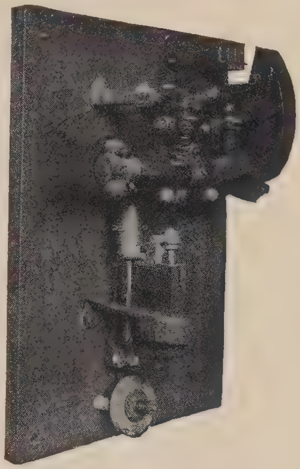


FIG. 133. Double-pole Contactor and Series Accelerating Relay

This contactor illustrates switches 2 and 3 in Fig. 132, with their respective relays.

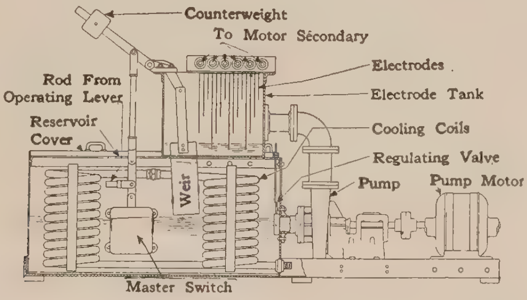


FIG. 134. Liquid Controller for Large Wound Secondary Induction Motors

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[2] This is shown in Fig. 40, Chapter V.

[3] As described in Chapter XIII.

[4] An analysis of the problem of unbalanced secondary operation is discussed in detail in a paper by Mr. A. A. Gazda, presented before the A. I. E. E. in February, 1917. His theoretical analysis was carefully checked by test so that the results given represent actual operating conditions.

In discussing this question the inductance and resistance of the secondary winding of the motor will be neglected for the sake of simplicity, as their effect is very small on the total results. Fig. 136 shows a simplified diagram of connections together with a sequence table. When the motor is first started the current in each phase of the secondary is equal and no unbalancing occurs. When switch No. 1 is closed, we will assume that the resistance in one phase is only half the value in the other two. The difference between the maximum and minimum currents in the secondary, however, is only 30 per cent. This is shown in Fig. 137. The normal full-load current in the secondary would take an intermittent value between the 100 per cent current in two of the phases and the 130 per cent current in the third phase. The actual full-load current corre-

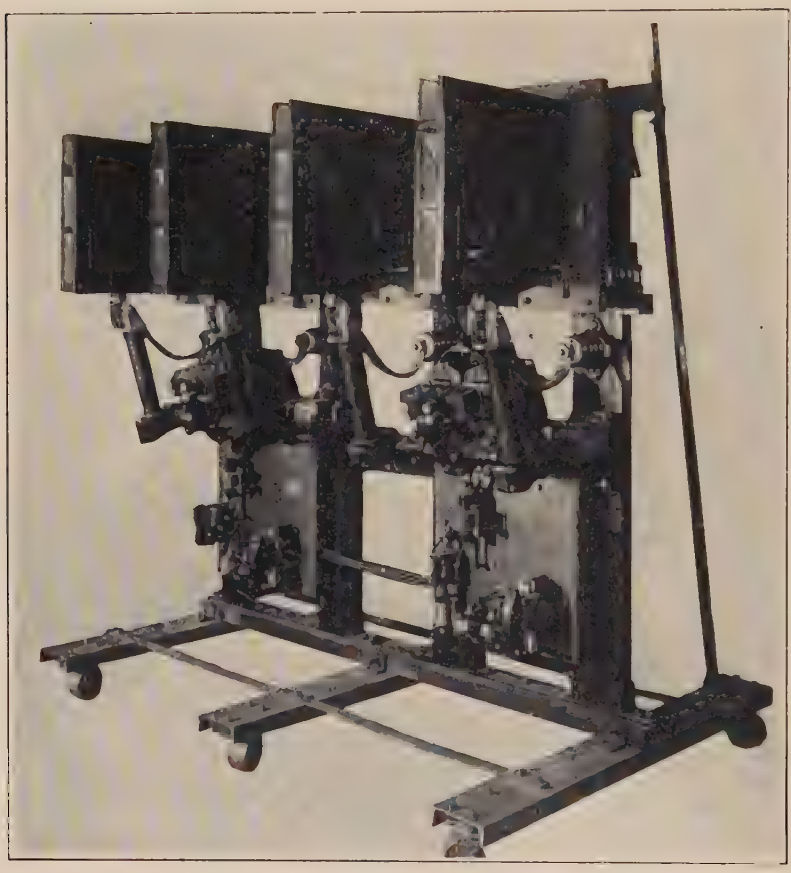
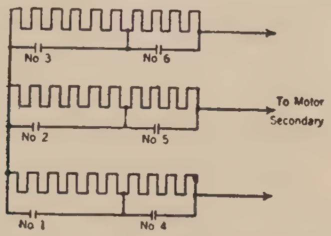


FIG. 135. 6600-volt, 500-amp. Air Break Contactor Panel

sponding to this condition wouuld be approximately 111 per cent which represents an overload in one phase of 17 per cent. Switch No. 2 is now closed, giving a low resistance in two phases and a high resistance in one. Fig. 138. Assuming the low value of current is 100 per cent, the other two phases will have current of 150 per cent. The equivalent balanced current for this combination is 135 per cent which represents an overload of approximately 11 per cent in two of the phases.



SW	RUN						
1		O	O	O	O	O	O
2			O	O	O	O	O
3				O	O	O	O
4					O	O	O
5						O	O
6							O

FIG. 136. Sequence of Switches

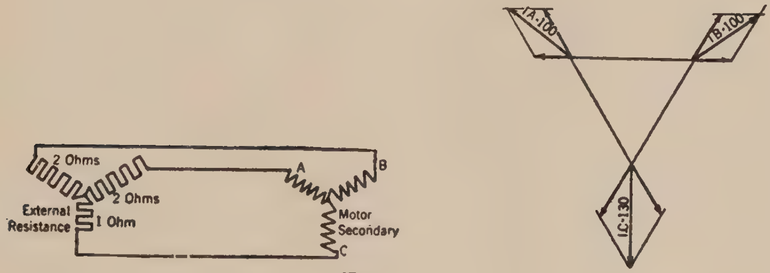


FIG. 137

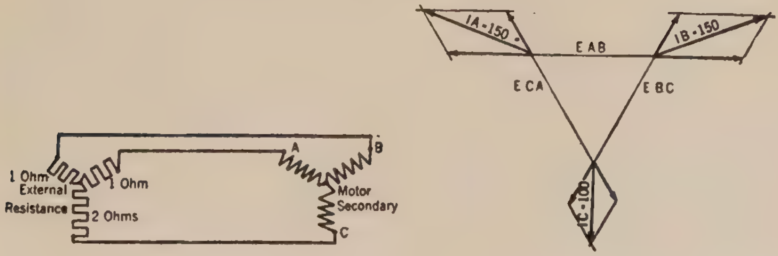


FIG. 138

When switch No. 2 is closed the currents in the three phases are balanced. Other values of resistance can be used and the analysis worked out for each combination.

Unbalanced currents in the secondary cause the primary to draw a low frequency current from the line. This is caused by the single phase component of the secondary field. Mr. B. G. Lamme in the Electric

Journal, Volume XII, page 394, has explained this very fully for the extreme case in which one phase of the secondary is open circuited. Fig. 139 is an oscillograph record showing this low frequency current in the primary.

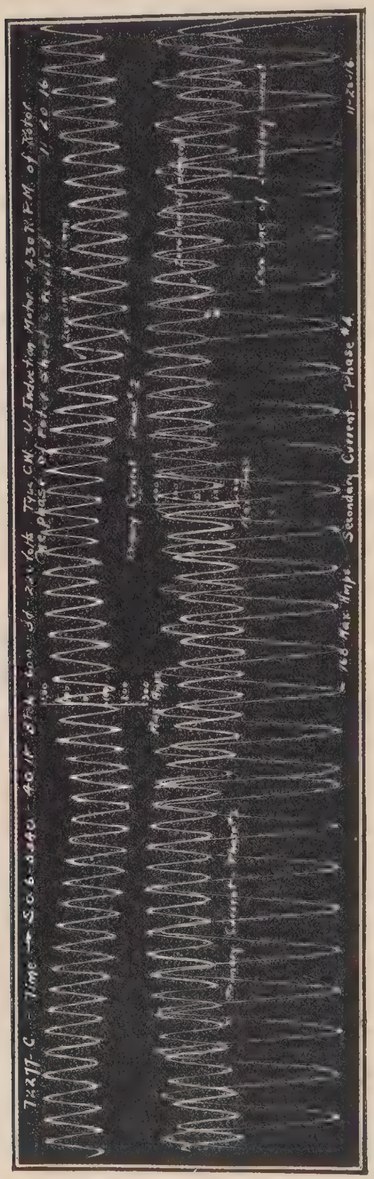


FIG. 139

The heating effect of the unbalanced currents in the secondary of the motor is distributed in proportion to the squares of these currents; the total heating being equal to the sum of the squares of the currents, thus $I_1^2 + I_2^2 + I_3^2$, or in other words, the heating in the motor is distributed throughout the motor and the rating of the motor is not limited by the maximum current in any one phase. These results have been verified by actual test. The secondary loss was found to be only 5 or 10 per cent higher unbalanced than balanced. (Table II.)

The rating of a motor of this type is dependent largely upon ventilation. When running at a slow speed the fan action of the rotor is very much less than at full speed. This fan action varies as the square of the speed. The load which the motor carries depends to a considerable extent upon this fan action, and, therefore, the temperature of the motor with a given torque will be much higher at a slow speed than at the high speed. The effect of this variation in speed is considerably greater than any effect due to unbalanced currents. In applying these motors, it is, therefore, necessary to limit their torque at slow speeds. This information can be obtained from the data furnished by the motor manufacturers.

Certain applications require a low initial starting torque. This can be very readily obtained by connecting the motor secondary in single phase, leaving one leg of the resistance open circuited. Under these conditions, the motor will exert a starting torque equivalent to approximately two-thirds of the torque which would be obtained with the same amount of resistance in each leg and all three legs in circuit. Since the first notch of the controller gives a relatively low torque not much work is being done by the motor and it is entirely satisfactory to operate single phase. This reduces the amount of resistance required. A standard controller can be connected as shown in diagram, Fig. 140, to give a single phase secondary operation on the first notch. If the resistance furnished with the motor gives half full-load torque with the secondary balanced on the first notch, the controller can be reconnected to start the motor single phase and obtain a starting torque of only 33 per cent of full-load torque. This is an easy way to adjust the starting torque where a low value of resistance required and reduces the amount of resistance required for a given installation.

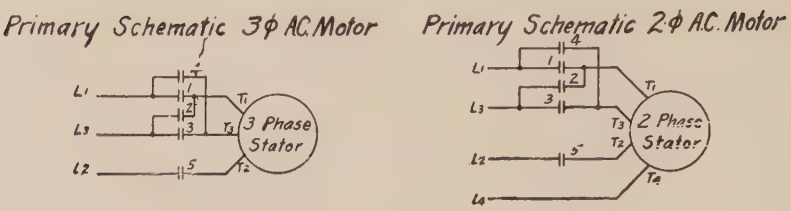
The speed torque characteristics of a polyphase motor operating with a single phase secondary winding are explained in Chapter XI and illustrated in Fig. 96.

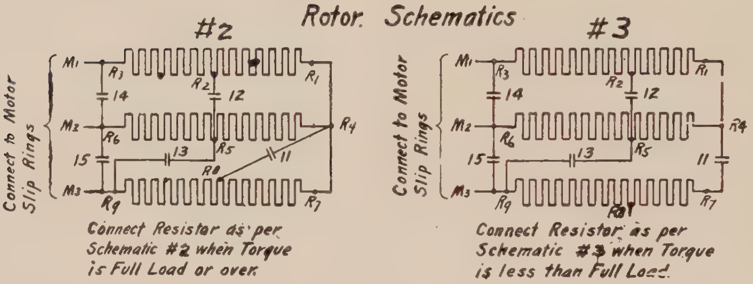
TABLE II.

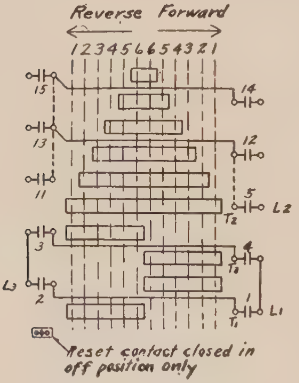
OPERATION OF 40-HP., 3-PHASE, 60-CYCLE, 220-VOLT INDUCTION MOTOR WITH VARIOUS VALUES OF EXTERNAL SECONDARY RESISTANCE

Resistance in Ohms per Leg			Primary Volts			Primary Amps.			Equivalent Balanced Pri. Amps. (r.m.s.)	Secondary Amps.			Equivalent Balanced Sec. Amps. (r.m.s.)	Speed in r.p.m.	Pound Feet Torque	Power Factor
0.81	0.81	0.81	220	218	220	114.8	109.2	110.8	111.8	77.2	76.8	76	76.7	415	242	78.6
0.81	0.81	0.39	220	218	220	117.7	110	114	114	64.4	90.1	79.2	78.6	520	242	77.15
0.39	0.39	0.81	220	218	220	117	110	114	113.8	90.6	62.3	79.5	78.4	600	242	77.5
0.39	0.39	0.39	220	218	220	111.7	104	110	108.7	75.2	75.2	74.8	75.15	660	242	79.7
0.13	0.13	0.39	220	218	220	114	108	112	111.4	90.7	55.4	81.7	77.2	768	242	78.4
0.39	0.39	0.13	220	218	220	114	108	111	111.2	63	92.6	72.4	77.1	723	242	78.2

For motors of 200 horse-power and larger, the secondary control often consists of a liquid controller, Fig. 134. Each phase of the secondary of the motor is connected to a series of iron plates. These iron plates extend down into a tank, which may be filled with an electrolyte, usually carbonate of soda and water. These plates are of different depths and so arranged that the number of plates, as well as the immersed area, increases as the water level rises. By properly proportioning these plates the desired acceleration can be obtained. In Fig. 134, the iron plates or

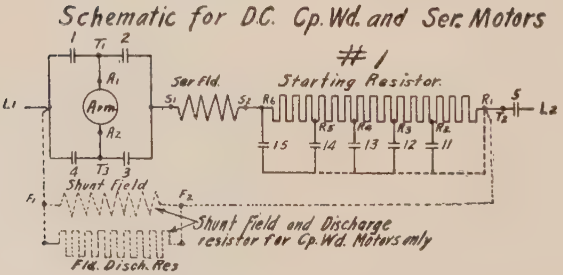



Rotor Schematics
#2
#3
Connect to Motor Slip Rings
M1
M2
M3
R1
R2
R3
R4
R5
R6
R7
R8
R9
11
12
13
14
15
Connect Resistor as per Schematic #2 when Torque is Full Load or over.
Connect Resistor as per Schematic #3 when Torque is less than Full Load.



Sequence Table

Sw.	Reverse 6	5	4	3	2	1	Off	Forward 1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3	○	○	○	○	○	○							
4								○	○	○	○	○	○
5	○	○	○	○	○	○		○	○	○	○	○	○
11	○	○	○	○	○				○	○	○	○	○
12	○	○	○	○						○	○	○	○
13	○	○	○								○	○	○
14	○	○										○	○
15	○												○



Note:– Connections shown dotted are to be made inside controller for D.C. motors only

FIG. 140. Diagrams for Cam Controller

electrolytes extend into the upper tank, while underneath is a larger tank used for storing and cooling the electrolyte. A centrifugal pump, driven by a small motor, lifts the electrolyte from the lower into the upper tank. A valve or weir in the upper tank can be adjusted to give any desired level, and is operated by the same lever that operates the master switch. A master switch controls contactors in the primary of the motor. A movement of the operating lever in either direction first operates the master switch to close the primary circuit of the motor with a small amount of electrolyte in the upper tank. A further movement of the lever increases the height of this electrolyte until full speed of the motor is obtained. The pump has only a limited capacity so that an appreciable time elapses between the movement of the weir and the increase in the height of the electrolyte; this time element can be adjusted so that the minimum period of acceleration is fixed at a safe value. The weir is large enough to permit the electrolyte to discharge very rapidly, so that when the lever is thrown quickly from the forward to the reverse direction the electrolyte will be at approximately its minimum level when the primary switches are reversed. The continual pumping of the electrolyte from the lower tank to the upper tank and the discharge through the weir causes a rapid circulation and dissipates the heat energy with a minimum amount of steaming.

The advantages of the liquid controller are: (1) Its simplicity; (2) its large thermal capacity, which enables it to sustain heavy overloads for short intervals of time, and (3) the absence of definite notches or steps, so that absolutely smooth acceleration is obtained. In this country there has been little demand for this form of controller in small sizes, partly due to a prejudice against the use of a liquid and partly because the other forms of controllers are usually cheaper for small motors.

Squirrel-cage Motors

The current taken by an induction motor in starting can be limited by placing resistance in series with the primary and using a short-circuited secondary. This form of secondary is commonly known as a squirrel-cage secondary and the motor is spoken of as a squirrel-cage motor. If resistance is used in series with the primary, the current will be reduced in proportion to the resistance inserted. The torque of the motor, however, will decrease as the square of the voltage across its terminals. This method of starting, Fig. 141, is very simple and inexpensive and is sometimes used with small motors. There are a few applications for large motors which will require 90 per cent of normal voltage to start where this form of starter would be more satisfactory than the transformer type.

The maximum current is taken at the time the motor starts from rest, and this current gradually decreases as the motor increases in speed, so that the voltage on the terminals of the motor will gradually increase, as the drop through the resistance is proportional to the current.

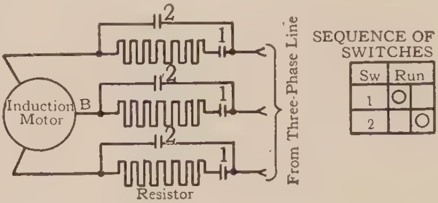


FIG. 141. Connections for Starting a Squirrel-cage Motor by Series Resistance

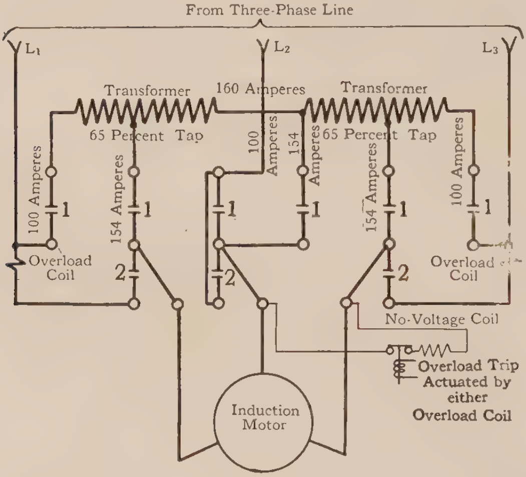


FIG. 142. Connections for Starting a Squirrel-cage Motor by an Autotransformer Starter

In the starting position contacts *1* are closed. In the running position contacts *1* are open and contacts *2* are closed. The amperes given are for the starting position only and are merely relative. The no-voltage coil serves to hold the handle in the running position against the action of a spring which returns it to the off position if the voltage is interrupted or reduced below a certain value. Either one of the overload coils will interrupt the circuit of this no-voltage coil.

Autotransformer Starters.—Nearly all squirrel-cage induction motors are started by using a transformer to apply a reduced voltage to the primary of the motor. The advantage of a transformer over a resistor is the fact that the reduced voltage is obtained with little or no loss in power, and therefore the current drawn from the line is less than the current taken by the motor in the ratio of the starting voltage to the line voltage. The connections commonly used for this type of starter are shown in Fig. 142. The transformer has only one winding and is usually called an "autotransformer." The complete device is often called an "autostarter" or a "compensator." The relative values of current in the different circuits during starting are shown on the diagram, not including losses in the transformer. These values of current are given merely to bring out the saving in power which results from this method of starting. The starting voltage is assumed to be 65 per cent of normal, which gives approximately 42 per cent of the torque which the motor would exert at standstill, if it were connected to full voltage. This starting torque of the motor at full voltage is usually from 150 to 200 per cent of full-load torque, so at 65 per cent of line voltage, the starting torque would be from 65 to 85 per cent of full-load torque, which is sufficient to start most loads. Other taps are provided on the transformer so that the starting voltage may be adjusted.

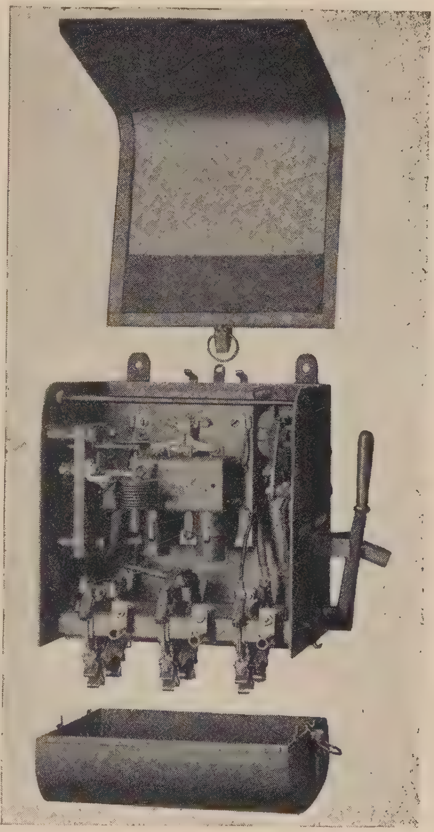


Fig. 143. Autotransformer Starter with Cover and Oil Tank Removed

Fig. 151 shows a vector analysis of the voltage and current in one of the phases of an autotransformer starter assuming 80 per cent of line voltage applied to the motor terminals. The same analysis is given in Fig. 150 for a starter using resistance to reduce the voltage of the motor to 80 per cent of normal at the time of starting. These two figures show that for the same starting conditions, the autotransformer starter takes about one-third of the power from the line and about 80 per cent of the current whent starting from rest. In both cases the wattless current is the same.

If 90 per cent of the line voltage is required to start the motor there is very little use of employing a transformer for starting purposes. Such a condition usually indicates that the motor is not suitable for the particular application; either a wound secondary motor should be used or a larger squirrel-cage motor. The starting torque of a squirrel-cage motor can be increased by increasing the secondary resistance. This, however, decreases the efficiency of the motor. Usually the secondary resistance of a squirrel-cage motor is adjusted by using different materials in the rings short-circuiting the secondary windings and is not

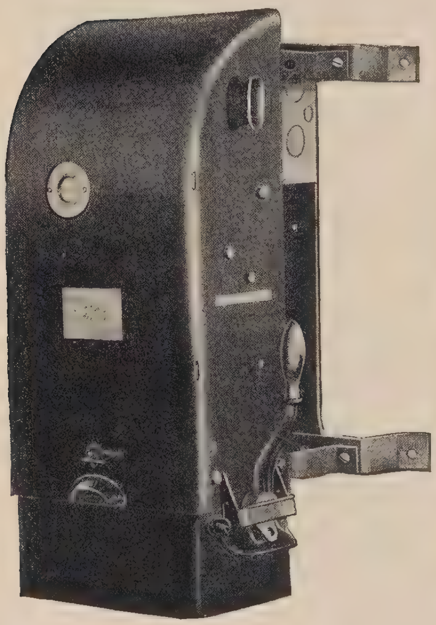


FIG. 144

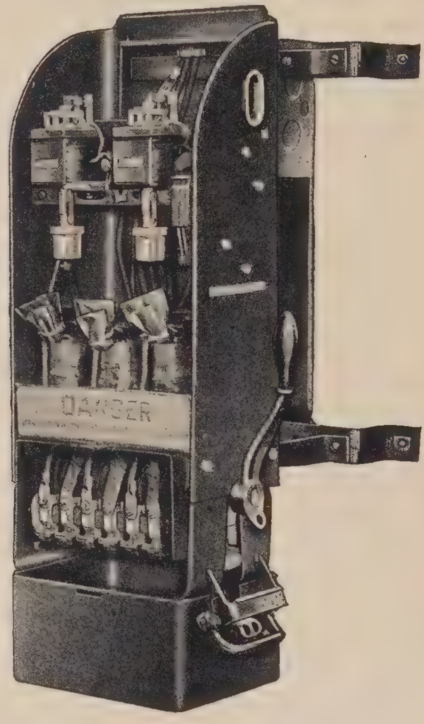


FIG. 145

Autotransformer—Manual Type

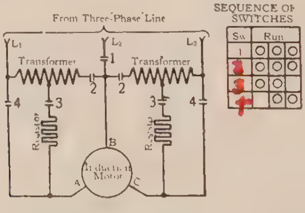


FIG. 146. Connections of Autotransformer Starter

With resistor to obviate opening the circuit when changing from starting to running positions.

adjustable after the motor is built. One method of increasing the starting torque of an existing motor is to saw slots in the short-circuiting rings between the connections to the winding bars. Where the motor is used for continuous operation and requires heavy starting torque it is undesirable to use a high-resistance secondary, and therefore the wound secondary motor is preferable.

A commercial starter for small and medium-sized motors is shown in Fig. 143. The switch in the lower part of the case is immersed in oil.

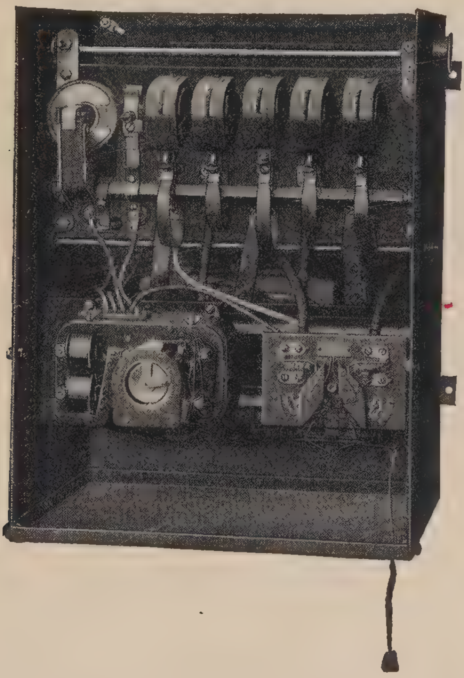


FIG. 147. Automatic Compensator with the Cover Removed and with Feet for Wall Mounting

Above the switch is the transformer, and in front of the transformer is located the overload protection. In the *off* position the handle stands central. To start the motor the handle is moved in the direction which closes the contacts marked *1*, Fig. 142. After the motor has accelerated to approximately full speed, the handle is moved in the opposite direction and the contacts, which are marked *2*, are closed. The handle is held in this position by a small magnet called the low-voltage coil, which releases the handle on the failure of voltage and allows it to return to the *off* position. A latch is usually provided to prevent the operator from accidentally throwing the handle into the running position first.

In passing from the starting to the running position with this arrangement, it is necessary to open the connections, so that the motor will not be connected to the starting tap on the transformer and at the same time connected to the line, as this would short-circuit a section of the transformer and probably destroy it. In starting large motors it is often desirable to pass from the starting to the running position without opening the motor circuit. This may be done by using a resistance connected as in Fig. 146. This resistance is inserted between the starting tap and the line to prevent short-circuiting the transformer at the time the connections are changed. In this arrangement the contacts marked *2* and *3* represent

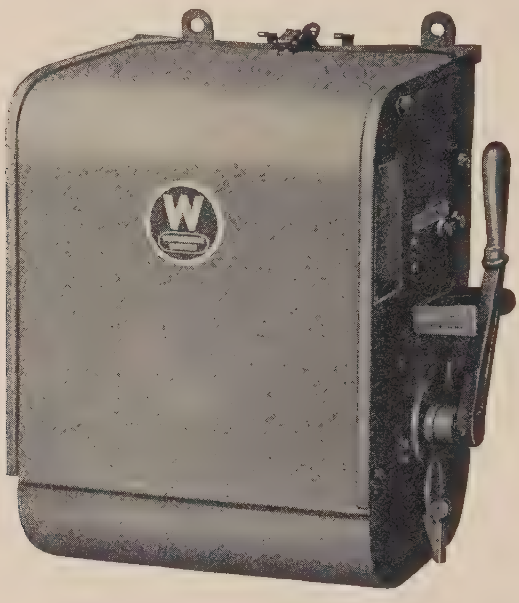
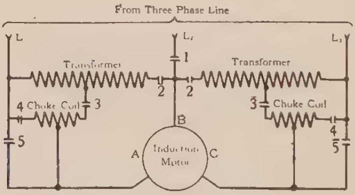


Fig. 148. External View of Autotransformer Starter



SEQUENCE OF SWITCHES

Sw	Run				
1	○	○	○	○	○
2	○	○			
3	○	○			
4		○	○	○	
5				○	○

Fig. 149. Connections for Multipoint Starting with an Autotransformer

the starting connections. They are not opened until after contacts *4* are closed.

Where several starting steps are used, the arrangement shown in Fig. 149 may be made. This makes use of a small autotransformer or coil, the center of which is connected to the motor load. After the autotransformer is energized, contact *3* of this auxiliary coil is connected to the starting tap. One-half of the coil then acts as a choke coil and gives the minimum starting voltage. When contact *4* is closed an intermediate voltage is obtained. Contact *3* is then opened and *5* closed, which connects the motor directly to the line, giving the final step in starting. This method makes a very simple set of connections for a magnetic contactor starter where a multipoint starter is required.

A modification of this arrangement is shown in Fig. 150. This arrangement is similar to Fig. 142 but the switches are operated in a different manner. The contacts marked *1*, *2* and *3* are first closed. This gives the same connection as closing contacts *1* in Fig. 142. If contacts *2* are now opened, one end of each autotransformer is disconnected from the line and the motor is left across the line with a part of the transformer winding in series, which acts as a choke coil. Switch *4* is immediately closed, connecting the motor to the line. This short-circuits a section of the transformer but, since the winding is not energized, no harm results. Switch *3* is now opened, disconnecting the motor from the transformer.

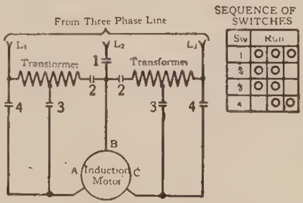


FIG. 150. Modified Method of Producing Multipoint Starting with an Autotransformer

Disconnecting the primary of an induction motor from the line when passing from the starting point to the running position makes very little difference with small motors. With large motors, however, in special cases, it may cause surges of current and voltage.[5] These surges are more apt to occur in high-speed than in slow-speed motors. They depend, however, upon the characteristics of the motor and can readily be taken care of by the manufacturer when he furnishes the motor and the starter as a combined unit.

The distribution of current within the windings of an autotransformer starter is somewhat involved, but an approximate analysis omitting minor factors is interesting and explains certain features which are not apparent without such an analysis. We will first consider the exciting current or magnetizing current as it is sometimes called. It is composed of two principal items, the magnetizing current, which is a zero power factor current, and the iron loss current, which is a 100 per cent power factor current. These two elements give a resulting current which is called the exciting current and which may have a power factor as high as the

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[5] This is brought out in Mr. Hellmund's paper on "Transient Conditions in Asynchronous Induction Machines and Their Relation to Control Problems," in the *Proc. A. I. E. E.*, Feb., 1917.

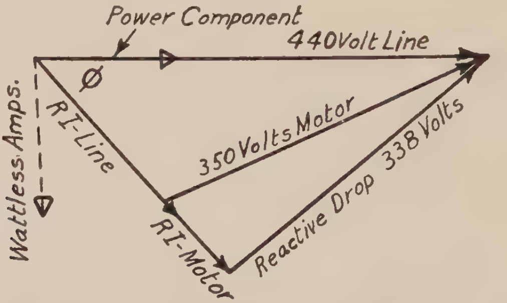

FIG. 151. Single-phase Diagram[6] of Circuit with Resistance for Starting to Give 80 Per Cent of Line Voltage at the Motor Terminals, Rotor Locked Conditions

Motor and resistance characteristics
  Resistance total 2.68 ohms.
  Reactance 3.20 ohms.
  Impedance 4.18 ohms.

Power taken from the line 29.6 kw.
Wattless current 80 amps.
Line current 105 amps.

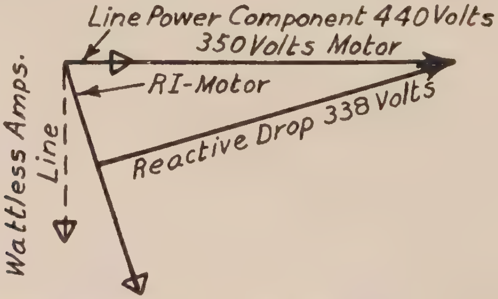

FIG. 152. Single-phase Diagram[6] of Circuit with Autotransformer for Starting to Give 80 Per Cent of Line Voltage at the Motor Terminals Rotor Locked Conditions

Motor characteristics
  Resistance 0.9 ohm.
  Reactance 3.2 ohms.
  Impedance 3.32 ohms.

Wattless current—80 amps.
Power taken from the line 10 kw.
Line current—84 amps.

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[6] The diagram shows the advantage of using a transformer instead of a resistance for squirrel-cage motor starting. A similar diagram with 65 per cent of line voltage at the motor terminals shows that the power taken from the line is nearly five times that taken with an autotransformer and the current 30 per cent greater. The transformer characteristics are neglected in the above analysis.

power factor of the induction motor when it is connected to the line and the rotor is stationary.

By referring to Fig. 153 it will be noted that the exciting current in the longer section of the autotransformer tends to flow in opposition to the motor load current. Since these two currents have power factors which are not far apart, the motor current neutralizes this magnetizing current, and it is possible so to proportion the motor load current that there will be very little current or I^2R loss in the larger part of the transformer windings. This condition is only approximated, as the motor current is not exactly in phase with the exciting current. It illlustrates, however, the fact that the magnetizing current actually reduces the I^2R loss in the larger part of the transformer windings. The two currents add in the small end of the transformer winding so that as the starting voltage is decreased the effect of this magnetizing current becomes more and more apparent. The current taken by the motor, however, decreases with the decreasing voltage so that one effect offsets the other to a considerable extent.

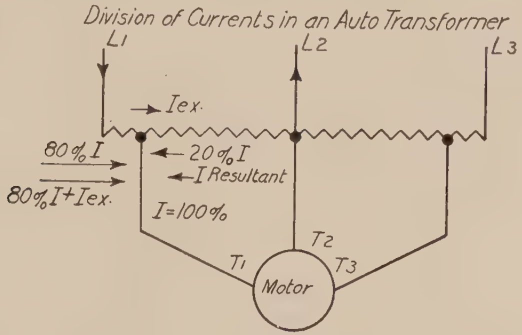

FIG. 153. Diagram Showing How the Exciting Current Cancels Out the Load Current in the Larger Part of the Autotransformer Winding

I—Load Current.

Iex—Excitation current of the transformer.

The load current represented as 100 per cent divides in proportion to the tap ratio. In the case shown with the 80 per cent tap, 20 per cent of the load current tends to flow through the large number of turns and 80 per cent through the small number of turns. But the exciting current and the load current in the large number of turns oppose. During starting, when the power factor of these currents is approximately equal, they subtract almost directly. The net resultant current, therefore, in the large number of turns is small and the consequent heating effect smaller, since the heating varies as the square of the current. These currents add in the small number of turns, but since this is a heavy winding designed to carry load current, the additional heating effect is small. The same effect takes place if the autotransformer is connected on the 65 per cent tap.

[illegible] 30 hp 4 p (2005) = [illegible] C 460 V.
∴ LRA = 276 A
65% = 145
140/8 = 82
[illegible]
current

The distribution of current in an autotransformer during the starting of the motor is further illustrated by Figs. 154 and 155. We will assume that the autotransformer starter has been designed for a 30-hp., 3-phase, 440-volt motor and that the root-mean-square current of this motor per phase during acceleration is 82 amperes when connected to 65 per cent of normal voltage (Fig. 154). We will also assume that the exciting current of the transformer is 22 amperes. The motor current is divided between section "a" and "b" of the transformer as follows: Section a, 53 amperes, and section b, 29 amperes. In section "a," the two currents add, making a total of 53 plus 22 or 75 amperes. In section "b" of the transformer the currents subtract, making a total of 29 minus 22 or 7 amperes. Since section "b" represents 65 per cent of the total winding, it is seen that the total heating in the transformer is reduced by the exciting current. If the motor is connected to the 80 per cent tap (Fig. 155), the heating in the transformer will be still less although the motor current is greater. This is because section "a" which carries the extra current is only 20 per cent instead of 35 per cent of the total winding space. This point has been demonstrated by actual tests.

Let us now assume that the 30-hp. starter was used for starting a 5-hp. motor, 3-phase, and 440-volt. The full-load current of this motor is approximately 15 amperes when connected to 65 per cent of normal voltage. This motor current is distributed in the transformer windings as follows: Section "a" 10 amperes and section "b," 5 amperes. We assumed above that the exciting current was 22 amperes. The total current in section "a" will, therefore, be 10 plus 22 or a total of 32 amperes as compared with 75 amperes for the 30-hp. motor. The current in section "b" will be 22 amperes minus 5 or 17 amperes total as compared with 7 amperes for the 30-hp. motor. The heating effect of the current in section b is, therefore, about six times as great for the 5-hp. motor as for the 30-hp. motor. If the 5-hp. motor is connected to the 80 per cent tap, the difference will be still greater.

These two examples show that a large starter used on a small motor may heat up more than if used with the motor for which it is designed. The two previous examples are exaggerated and the currents do not cancel to the full extent shown due to the differences in phase angles, as the examples are simplified to make them easy to follow. In making applications of starters to smaller motors, care must be exercised. It is evident that if the exciting current were zero or had a very small value, an advantage would be gained by using a large starter with a small motor in the same way that a resistor will heat up less with a small motor than a large one. This, however, makes a very poor transformer when used with a motor to the full hp. rating. The exciting current should be made high enough to reduce materially the heating on the 65 or 80 per cent tap.

From time to time, some one measures the exciting current of an autotransformer starter at no load and is surprised to find it quite large. This is true, and the heating effect will naturally be considerable if left on long enough. If this test is carried a little further and the motor connected to the circuit with its secondary locked in a stationary position and the in-put current both from the line and in the motor, accurately measured, it will be found that by decreasing the motor current in the ratio of the transformation and subtracting this from the total in-put current the magnetizing current has added in many cases less than 5 per cent to the total current. This is true of the 65 per cent tap. If these tests are now

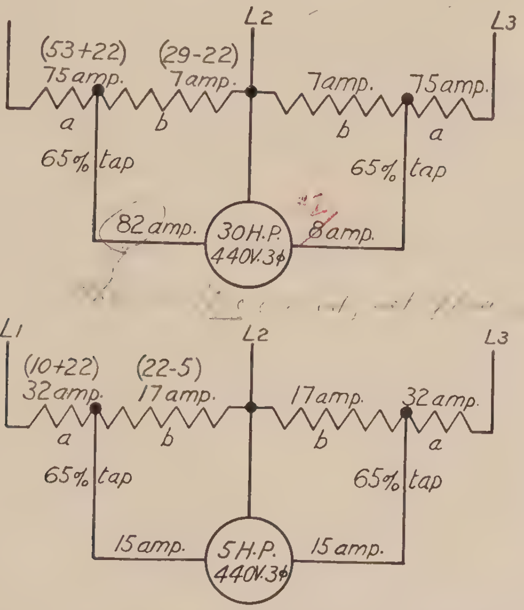

FIG. 154. Diagram—30-hp. Autotransformer Starter Connected to 65 Per Cent of Normal Voltage

The diagram shows the distribution of current during the starting period based on the root mean square value of the motor current during acceleration. It is assumed that the exciting current is 22 amperes and approximately in phase with the motor current. This assumption is not strictly correct as the phase angles of the various components of the current are unsymmetrical and the current values do not add or subtract directly. The current components also differ in each of the two phases. The diagram is made approximately correct for purposes of illustration and, therefore, does not take into account the minor differences enumerated above repeated on the 80 per cent tap the increase in the total current on account of the magnetizing current will be found to be still less.

Another way to analyze the problem is to consider that the magnetizing current taken by the motor is fixed for a given voltage. The autotransformer furnishes this magnetizing current to the motor. If we consider the section of the transformer between the motor terminals we will find that the magnetizing current required by the transformer is approximately 180° out of phase relation with the magnetizing current taken by the motor. This results in the magnetizing current of the one canceling that of the other. If these magnetizing currents are equal there will only be a small flow of current in this section of the transformer due to a difference of phase relation between the currents.

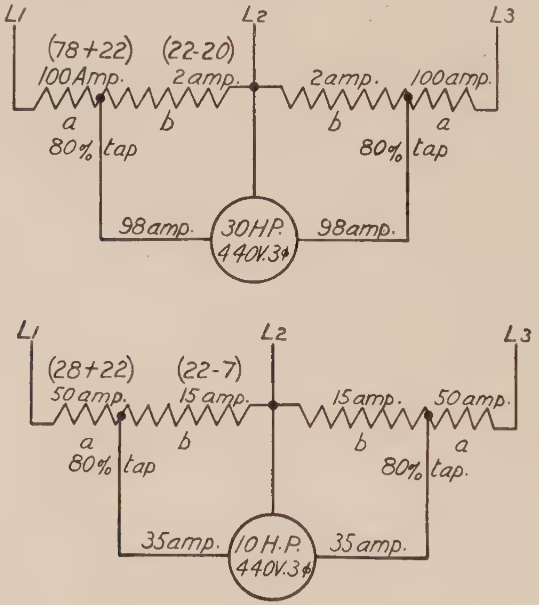

FIG. 155. Diagram—30-hp. Autotransformer Starter Connected to 80 Per Cent of Normal Voltage

The diagram shows the distribution of current during the starting period based on the root mean square value of the motor current during acceleration. It is assumed that the exciting current is 22 amperes and approximately in phase with the motor current. This assumption is not strictly correct as the phase angles of the various components of the current are unsymmetrical and the current values do not add or subtract directly. The current components also differ in each of the two phases. The diagram is made for purposes of illustration and is, therefore, only approximately correct and does not take into account the minor differences enumerated above.

The section of the transformer winding between the motor terminals and the line and designated as section "a" in Figs. 154 and 155, has a magnetizing current flow through its windings which is not neutralized by the magnetizing current of the motor. The two magnetizing currents add vectorially and tend to heat these windings due to the I^2R loss. If the resistance of this portion of the winding is kept low the actual wattage loss is also low, this being only a question of design.

Let us now consider the current taken from the line. This is made up of two components, one the energy component and the other the magnetizing component. If the magnetizing current of the motor subtracts from the magnetizing current of the transformer in section "b" (the long section), the heating effect in this section is comparatively small. By properly designing the short section of the transformer winding (section "a") so as to keep down the I^2R loss therein the total loss in the complete transformer can be made quite low. This condition is obtained by having the transformer exciting current approximately equivalent to the exciting current of the motor and holds good for only one particular size and design of motor. When designing commercial autotransformers, it is necessary to select a certain range of motor sizes and speeds and select a motor magnetizing current which represents the average value and then make the magnetizing current of the transformer equal to this value. The windings of the transformer must be proportioned for the worst condition, which is obtained in section "a" of the winding when the largest motor is being used and in section "b" of the transformer winding when the difference between the motor magnetizing current and the transformer magnetizing current is a maximum. An additional allowance must also be made for small differences in phase angles.

It will be seen from the above that the exciting current of a properly designed autotransformer for intermittent starting should be much larger than for power transformers. This excess magnetizing current will overheat section "b" of the transformer winding if left on for any considerable length of time without the motor load, because there is no cancellation of current in this section of the transformer winding.

The exciting current varies with the voltage and the frequency. Each time the magnetism in the iron reverses it generates a voltage in the transformer windings. The product of this magnetism multiplied by the number of turns in the coil multiplied by the frequency must balance the line voltage. Since the number of turns in the coil has a fixed value for a particular design an increase in voltage at a constant frequency would require a corresponding increase in magnetism in order to balance this increased line voltage. If the voltage remains constant and the frequency decreases, an increase in magnetism would be required to make the product constant. When the iron in the autotransformer is worked pretty hard, as is the case in the starting transformers, an increase in magnetism requires a considerable increase in exciting current, the iron loss going up quite rapidly at this part of the magnetization curve. Therefore, any unusual increase in voltage or decrease in frequency will cause a proportionally larger increase in the exciting current. Standard autotransformers are designed and guaranteed to operate successfully on 10 per cent variation in the line voltage provided the frequency remains constant. The converse is also true, viz., if the line voltage remains constant, the frequency may vary 10 per cent. This, however, is a rather unusual condition.

The torque of an induction motor varies as the square of the voltage. It is usual to express the starting characteristic of an induction motor by stating that it has a certain locked torque. This is the torque exerted when the rotor is stationary and normal voltage is applied to the primary windings. This torque is usually expressed in terms of the full-load torque. Thus, a motor having a locked torque of two, means that the torque at zero speed is equal to twice full-load torque with normal voltage on the primary. If 70 per cent of voltage were applied to the motor primary, the motor would exert a torque equivalent to two multiplied by $(7/10)^2$ or 98 per cent of full-load torque. The torque at any other starting voltage can be obtained by expressing this voltage in percentage, squaring it and multiplying by the locked torque given in per cent of full-load torque.

This starting torque is independent of the method employed for obtaining the reduced voltage. Sometimes the claim is made that a certain motor will start with one style of starter and not with another, the inference being that the starters have different effects on the starting torque of the motor. This is only true if the starters provide different voltages at the motor terminals. The taps on an autotransformer are usually expressed in percentage of full voltage. These percentage ratios are not exact, as it is necessary to compensate for the voltage drop through the transformer. This compensation differs with different motors owing to the variation in the starting current. It is, therefore, improbable that two different makes of autotransformers would give exactly the same voltage at the motor terminals and this is probably the explanation of the failure of one type to start the motor, while the other was successful. The difference in voltage may seem trivial, but it must be remembered that this difference is squared and that a little extra torque may be all that was required to break the load from the static position and allow the motor to start rotating. As soon as the motor commences to rotate the friction decreases and the torque of the motor gradually increases, so that the critical period is the instant of starting from rest. Sometimes the torque of a motor slightly varies when starting from rest, depending upon the location of the rotor slots relative to the primary winding. This variation of starting torque is usually quite small, but may be appreciable in particular motors; it, therefore, should be taken into consideration in comparing starters.

The starting voltage can be adjusted by changing the starting connection from one transformer tap to another. Standard transformers provide for 65 per cent and 80 per cent taps. This gives 42 per cent and 64 per cent locked torque of the motor when starting.

Where intermediate values of starting torque are necessary, they can be obtained by connecting one starting lead to the next higher starting tap, for instance, if one side is connected to the 65 per cent tap and the other side to the 80 per cent tap, an intermediate value of starting torque will be obtained with an intermediate value of power input. Connections of this kind unbalance the phase so that more current is taken from one phase than from the other. The amount of this unbalancing, however, is considerably less than the difference in voltages after the motor begins to revolve. In no case is the current taken from either phase greater than would be taken if both leads were connected to the higher voltage. Table III gives the results of a test made with both balanced and unbalanced connection, and shows the torques and voltages at the motor terminals.

The use of two autotransformers in a "V" connection for starting three-phase motors, is sometimes criticised on the ground that it produces unbalanced voltages at the motor terminals, and therefore decreases the starting torque of the motor. The tests in tables III and IV show that there is very little unbalancing and that the amount is negligible. The torque exerted by the motor in starting from rest is practically the same as with the three transformer arrangement. The variations in the starting torque exerted by different motors of the same design due to irregularity of manufacture is considerably greater than the effect of slight unbalancing.

The Electric Power Club has agreed that the standard starting period for manually operated autotransformer starters will be fifteen seconds. This is simply an arbitrary designation and means nothing unless a careful study is made of the effects of starting on the transformer. It does not mean that if the starting period exceeds fifteen seconds for one start that the transformer will be injured.

About 1912 the National Board of Fire Underwriters agreed with the manufacturers to use an arbitrary "stand" test for autotransformer starters. This test consisted in connecting the line wires to full voltage and applying three times full-load motor current to the starting tap, the

3. 360.5
2.0
1.6 /100
120
=1.7%

TABLE III

Test on a 100 Horsepower, 220-Volt, 60-Cycle, 3-Phase Motor with a Type A Auto-Starter Showing Voltages and Starting Torques of the Motor with Balanced and Unbalanced Tap Connections

Test on 65% Tap, Motor Locked

	Line Volts		Volts at Motor Terminals	Motor Torque
	No load	With load		
L¹ to L³	230	199	118.5	278 lb.-ft.
L² to L³	229	196	120	
L¹ to L²	229	194	122	

Test with One Winding Connected on the 65% Tap and the Other on the 80% Tap

L¹ to L²	229	190	130	34 lb.-ft.
L² to L³	229	184	141	must be
L¹ to L²	229	193	121	340 at least

Test with 80% Tap

L¹ to L²	229	188	141	410 lb.-ft.
L² to L³	229	185	139	
L¹ to L²	229	188	141	

These tests show that the transformers in V connection give nearly balanced voltages with unbalanced taps. The starting torque~~s~~ obtained with unbalanced taps is approximately the average of the two torques that would be obtained with either balanced connection.

TABLE IV

Comparative Test on a 3-Phase, 60-Cycle, 6-Pole Squirrel-Cage Motor Showing Starting Torque with Auto-Transformers in Open V and in Y 100% of Rated Voltage Applied to Transformer Windings

Motor Torque	Three Transformers in Y Connection	Two Transformers in Open V Connection
At 65% Voltage	33.5% of Locked Torque 34.3% of Locked Torque	33.1% of Locked Torque 34.0% of Locked Torque
At 80% Voltage	52.0% of Locked Torque 52.4% of Locked Torque	51.7% Locked Torque 52.2% Locked Torque

starting tap to be selected from 40 per cent to 65 per cent of line voltage. With these connections the line voltage was impressed on the starter for fifteen seconds every four minutes. The remaining three and three-quarter minutes were allowed for the transformer to cool. This test was repeated for one hour, which is equivalent to fifteen starting periods, and was based on the assumption that the heating effect in the starter was equivalent to that which would occur in starting under abnormal conditions. The test under these extreme conditions was to determine the probability of a starter becoming a fire hazard.

Since that time manufacturers have been designing their autotransformers to meet this test without being destroyed.

It should not be assumed, however, that a commercial starter can be applied where it is necessary to start as frequently as indicated by this test. Standard starters may be used for accelerating motors where the starting period is approximately fifteen seconds, and not over six or eight starts are made without allowing the transformers to cool down to the room temperature. Several starts of a longer period, even as long as thirty seconds, can be made if the transformer is cold and the starts not repeated too often. The curve, Fig. 156, indicates the relative increase in temperature under different starting conditions.

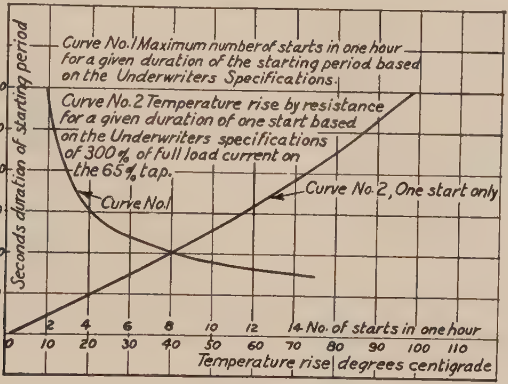

FIG. 156. Temperature Rise Under Different Starting Conditions

Many starters can be used on other voltages and frequencies than those for which they are rated; but in making such interchanges, it should be remembered that we have three elements to consider:

(1) The autotransformer.
(2) The low-voltage coil.
(3) The overload relay.

The low-voltage coil is independent of size of the motor but is sensitive to changes in voltage or frequency as the excess voltage will cause it to overheat and on a low voltage it will fail to hold. A decrease in voltage together with a decrease in frequency will counterbalance each other. For instance, a 550-volt 60-cycle coil operates successfully on a 460-volt 50-cycle circuit.

The autotransformers should not be used on voltages more than 10 per cent in excess of the normal rating, but they may be used for any voltage of less value provided that the current of the motor does not exceed the normal value for that particular transformer. For instance, the 30-hp. 440-volt autostarter can be used with a 15-hp. 220-volt motor by changing the low-voltage coil. It is obvious that if the current value is kept the same, the overload relay will not be affected. If the frequency is decreased the voltage should also be decreased, as, for example, the 550-volt 60-cycle transformer can be used on a 440-volt 50-cycle circuit for a motor which is smaller than the rating of the transformer proportionally to the decrease in voltage.

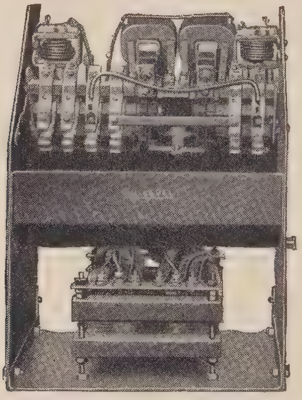

FIG. 157. Automatic Compensator with Top and Front Plate Removed

FIG. 158. Control Station

If the frequency is above normal, such as a 25-cycle starter being used on a 40-cycle circuit, the transformer will still be satisfactory, and if the size of motor is kept the same the same starter can be used by changing the low-voltage coil. The low-voltage magnet is provided with a brass shading coil for 60-cycle, and a copper shading coil for 25-cycle circuits, so that a change in frequency over this range may require a change in the shading coil if the best results are to be obtained.

Automatic acceleration for alternating-current controllers at present is limited to the series relay method or a time-element method. The time-element method is very satisfactory where the timing device can be relied upon. For rapid acceleration and reversing service, the series relay method,[7] shown in Fig. 132 is the best method to use.

SUMMARY OF CHAPTER XV

Examples of types of controllers used with wound secondary induction motors:

SERVICE		PRIMARY CIRCUIT	SECONDARY CIRCUIT
nonreversing	(small motors)	knife switch and fuses	face plate
	(large motors)	circuit breaker	drum
reversing	(small motors)	drum	drum
	(large motors)	magnetic	magnetic
automatic acceleration		magnetic	magnetic

In changing the design of primary circuits of a motor and controller to accommodate different voltages, usually the same motor secondary and hence the same secondary controller are used.

WOUND SECONDARY INDUCTION MOTORS may be accelerated or their speed controlled:

(1) By shortcircuiting sections of resistors inserted in the three legs of the three-phase secondary circuit (a) simultaneously in all three legs (balanced method) or (b) in one leg at a time (unbalanced method). As the heating effect is distributed, the secondary losses increased only five to ten per cent, and less apparatus is required, the latter method is sometimes preferable. By starting single-phase (=with one leg of the secondary open) reduced (two-thirds of normal) starting torque may be obtained, with less starting resistance. However, the ventilation, upon which the heating effect mostly depends, varies as the square of the speed and at reduced speeds the torque must be restricted.

(2) (For large motors.) By varying the immersed area of (iron plate) electrodes in (water and carbonate of soda) electrolyte (liquid controller). This is a simple method with large thermal capacity and smooth acceleration, but expensive in small sizes and open to the prejudice of some against the use of liquids in controllers.

SQUIRREL-CAGE INDUCTION MOTORS may be started:

(1) By inserting resistance in the primary circuit to vary the primary voltage.

(2) By using an autotransformer in the primary circuit with (usually 65 per cent and 80 per cent) taps to supply reduced voltage to the motor terminals. This method avoids resistance losses and (when supplying 80 per cent of normal voltage at the motor terminals) consumes four-fifths as much current and one-third as much power as the resistance-in-primary method.

If 90 per cent of line voltage is required to start a squirrel-cage motor, usually a larger motor or one of the wound secondary type should be used. The starting torque of squirrel-cage motors may be increased (but the efficiency decreased) by using higher resistance (brass) bars in the rotor, or by sawing slots in the short-circuiting rings. For heavy starting torque and continuous duty the wound secondary type is preferable.

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[7] Described in Chapter VII.

In comparing starting tests of motors with different autotransformer starters the following points should be noted:

(1) The voltage actually supplied by each to the motor terminals (the starting torque varies as the square of the voltage).

(2) In some motors the position when starting of the rotor slots relative to the primary winding as this affects the starting torque.

In an autotransformer starter, when the handle is thrown from the starting to the running position, usually the motor is disconnected entirely during the transition period, but for large motors a resistor is sometimes connected in the circuit during this period to avoid opening the line.

The exciting current (consisting of a zero power factor, magnetizing, component, and a 100 per cent power factor, iron loss, component) adds to the motor load current in the short section of the autotransformer winding, but in the long section opposes and cancels it. The exciting current of a starting autotransformer exceeds that of a power transformer, and is surprisingly large on no load, but by reason of its canceling function should approximately equal the exciting current of the motor with which it is used and on full load actually adds less than five per cent to the total current.

The National Board of Fire Underwriters requires an autotransformer starter to withstand without injury a one hour test of fifteen 15-second starting periods at four-minute intervals.

In using autotransformer starters on voltages and frequencies other than those for which they were designed, attention must be given to the autotransformer, the low voltage coil, and the overload relay, as to whether they should be changed.

Automatic acceleration of squirrel-cage induction motors is obtained by the time element and series relay methods.

CHAPTER XVI

SYNCHRONOUS MOTOR CONTROL

Two methods of automatic starting of synchronous motors—field frequency method—time-element method—starting of high voltage synchronous motors—starting on line voltage—manually operated starters—emergency stop—power factor correction.

Synchronous motors are coming into general use because they can be used for power factor correction as well as for driving machinery. The synchronous generator is one of the oldest forms of electrical machinery and is fully described in textbooks and well understood by electrical engineers. The synchronous motor construction is identical with and has the same characteristics as the generator, except that the operation is reversed. Electric power is supplied to the primary of the synchronous motor and converted into mechanical work by the rotation of the motor. Power factor correction is obtained by adjusting the strength of the d-c. field. A separate source of power is required for furnishing the direct-current supply to the field.

More care is required in starting a synchronous motor than an induction motor because the former must be brought into synchronism with the a-c. supply circuit. During the starting period it is necessary to manipulate the field and other circuits and it is therefore safer and better to use an automatic controller than a manual controller.

The torque required for starting the motor from rest and bringing it up to synchronous speed is obtained by means of damper windings which function in the same manner as the secondary of a squirrel-cage induction motor. The primary is connected to the source of supply frequency at reduced voltages by means of an autotransformer. The primary winding develops a rotating magnetic field which induces a current in the damper windings. The reaction between these windings exerts a torque which accelerates the motor. The damper windings are useful for obtaining stable operation of the motor after it has been synchronized, eliminating hunting or a tendency for the speed of the motor to oscillate above or below synchronism.

The starting torque of these motors is approximately the same as a standard induction motor having the same number of poles. It is practicable to build synchronous motors for much lower speeds than induction motors. Increasing the number of poles of synchronous motors increases the size for given horsepower ratings but does not introduce any serious difficulties in the electrical design. On the other hand a large number of poles in the primary of an induction motor causes excessive leakage and poor power factor. For this reason low speed motors are usually of the synchronous type. The starting torque of the low speed synchronous motor is low on account of the large number of poles required to give low speed operation. Four or six pole synchronous motors will exert considerable torque at starting.

The torque limitations of a synchronous motor occur as the motor approaches synchronous speed. An induction motor operates at several per cent below synchronism, the difference in speed or slip of the motor generating a sufficient voltage in the secondary to circulate the current necessary to develop the torque required by the load. When the synchronous motor reaches two or three per cent of synchronous speed the torque necessary for pulling the motor into synchronism is obtained by energizing the d-c. field magnets. These magnets react on the primary and develop an oscillating torque. This torque is positive during most of the cycle, the period of negative torque being short. The closer the motor is to synchronous speed the longer the period of positive torque. This oscillating torque swings the rotor into synchronism and locks it in at this speed.

If full field strength is applied when the motor is running at too low a speed, the proportion of negative torque will be much larger and may be sufficient to prevent the motor from accelerating to full speed. When a direct connected exciter is used it is often practicable to close the circuit of the field windings through this exciter when the synchronous motor starts from rest, as the d-c. machine is self-excited and does not build up its voltage until the motor has approached full speed.

The method of handling the field circuit of the synchronous motor differs for motors of different designs. In order to obtain the best results it is necessary to co-operate with the motor designer and select the arrangement of field circuits which will give the best results.

There are two general methods for the automatic starting of synchronous motors, both methods providing for changing the field connections when the motor reaches synchronous speed. Both methods may be used for starting at a reduced voltage with an autotransformer or for connecting the motor to full voltage. Both schemes of control are modified if a direct connected exciter is used. For the purpose of this discussion these two methods will be known as

(1) the field frequency method;
(2) the time-element method.

Field Frequency Method

When the motor is at rest and the field circuit is closed upon itself the rotating field set up by the primary of the motor will cause an alternating-current to flow in the closed field circuit, due to transformer action. When the rotor is at rest the frequency in the field circuit will be the same as the line frequency. As the motor increases in speed the frequency field circuit decreases but the maximum current remains substantially constant. As soon as the rotor reaches synchronous speed the current in the field circuit drops to zero very abruptly, as shown in Fig. 159, and can be used to operate automatic means for changing the motor connections from starting to running.

One method of accomplishing this is to provide a double throw contactor having two magnets. The upper magnet is energized from direct-current and tends to close the upper set of contacts; the lower magnet has its windings in series with the field. The contactor normally has the lower contacts closed and the lower magnet circuit connected to the motor field. In starting the voltage induced in the field windings maintains the lower contacts closed by means of the magnet. When the motor reaches synchronous speed the lower magnet is deenergized due to the induced voltage in the field windings reaching zero. This permits the magnet at the top of the contactor to open the lower contacts and close the upper contacts, in this way initiating the necessary connections for changing the controller from the starting to the running position.

Figs. 160 and 161 illustrate one form of an autotransformer type of automatic starter for a three-phase synchronous motor.

Magnetic contactors acting as starting and line switches are here employed to make the required connections between the electric power line, autotransformer and motor. There are two control circuits, one of alternating-current for the main contactors and their relays, the other being a direct-current control circuit for the field contactor and transfer relay. In the off position all main contactors and the upper contacts of the double throw field contactor *F* are open; the lower contact of the field contactor is closed. This makes a closed circuit through the motor field winding, the field discharge resistor, the field ammeter and the field rheostat for a portion of the starting period. This starter operates as follows:

(1) The start push button is closed by the operator, which closes auxiliary contactors *E* and *A*, Fig. 160; they in turn close main contactors *1*, *2* and *3*. This operation causes alternating-current at reduced voltage to flow through the three-phase motor windings. The revolving field starts to rotate and gradually accelerates to near synchronous speed.

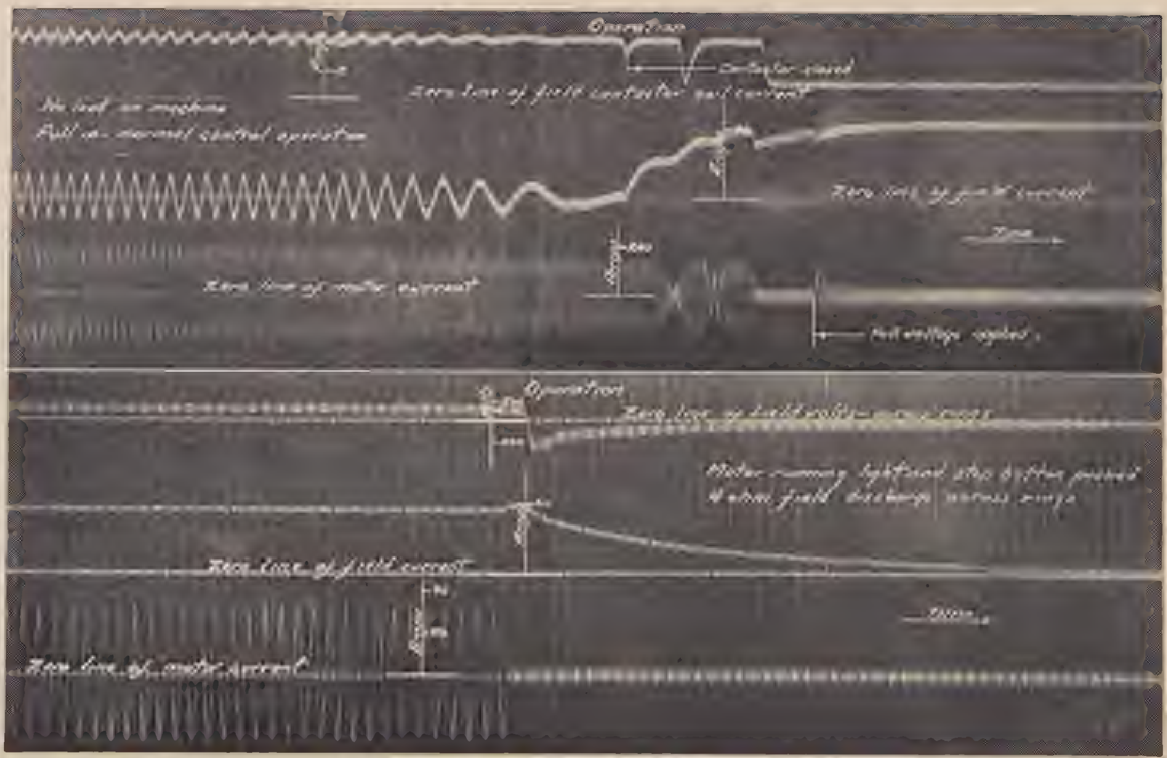
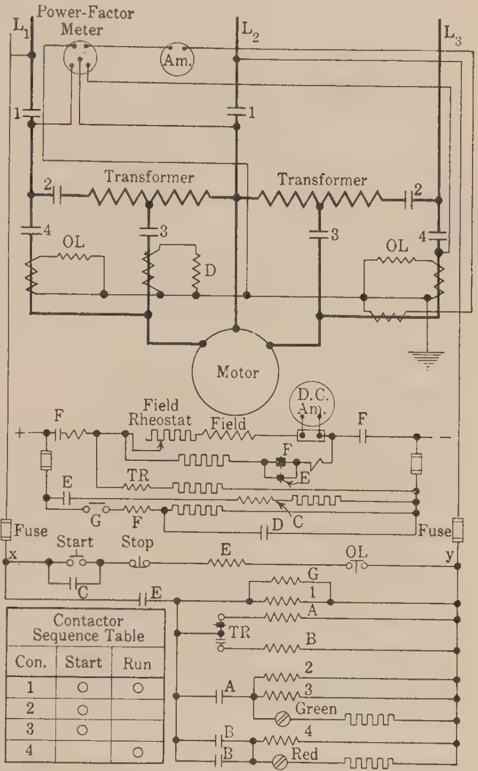


Fig. 159 Oscillograms Showing Actions Occurring During Starting and Stopping of a Synchronous Motor when Using the Field-frequency Type of Automatic Starter

(2) When the motor speed approaches synchronous speed the field contactor *F* automatically opens its lower contact and closes its upper contacts due to the fact that its upper electromagnet now overpowers the lower electromagnet, which has no voltage applied to its terminals when the motor reaches synchronous speed. This operation applies the direct-current excitation voltage to the motor field winding connected in series with a motor field resistor or rheostat, set to give minimum current in the stator windings for normal running conditions.



Con.	Start	Run
1	○	○
2	○	
3	○	
4		○

Fig. 160.—Simplified Diagram of Connections of Field-frequency Type Starter for Three-phase Synchronous Motor

(3) The transfer relay *TR* now being energized operates to open auxiliary contactor *A*, and therefore main contactors *2* and *3* and immediately closes auxiliary contactor *B* which in turn closes main contactor *4*. This operation opens the connections to the starting autotransformers and connects the motor stator windings directly to the three-phase electric power line so that the motor operates at full line voltage and with excited field. This completes the starting operation.

(4) To stop the synchronous motor the operator pushes the stop push button, which opens auxiliary contactor *E*, which in turn opening main contactors *1* and *4*. Opening auxiliary contactor *E* opens both control circuits and immediately inserts the field discharge resistance, preparatory to the operation of the field contactor *F*. When main contactor *1* is opened its interlock (or relay opening with it) opens the field contactor *F*, and thus removes the excitation from the synchronous motor field winding only after the stator windings have been disconnected from the power line. The transfer relay *TR* opens its run contactor and closes its starting contacts in readiness for another start. The starter is now in the off position.

Fig. 159 also indicates the action that occurs in stopping a synchronous motor with the type of automatic starter illustrated. This shows that there is no abnormal voltage induced in the field during stopping.

Green and red lamps indicate starting and running positions of the starter.

Low voltage protection is provided. On failure of alternating-current voltage all auxiliary and main alternating-current contactors open and this action opens the direct-current contactors and relays as well. When the direct-current voltage fails or the field excitation is lost the field contactor and transfer relay open and auxiliary contactor *C* is also deenergized. The latter opens the alternating-current control circuit by opening auxiliary contactor *E*, which in turn opens the main contactors *1* and *4*. This brings the starter automatically to the off position.

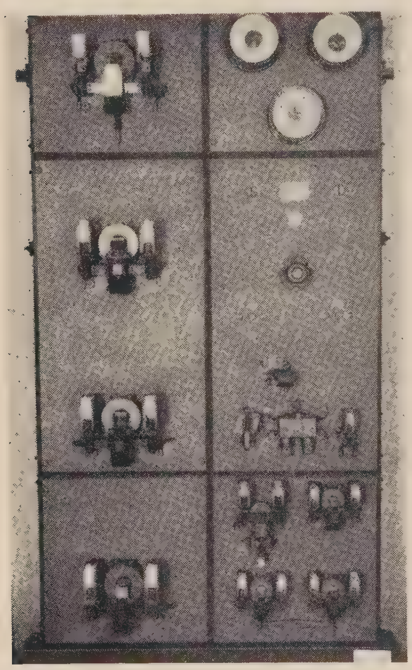


Fig. 161. Panel of a Field-frequency Type Controller for Synchronous Motor

Overload protection is obtained by the use of an overload relay giving inverse time limit protection. The relay contacts open under overload conditions and deenergize the coil of auxiliary contactor *E* which when opened for any cause automatically completely disconnects the motor from the lines. The overload relay is reset by hand after the trouble has been eliminated.

The main scheme of connections is shown for three-phase synchronous motors. The scheme may be applied to two-phase synchronous motors without a change in the number of contactors or autotransformers but with minor changes in wiring, as in the case of automatic starters for squirrel-cage induction motors. (Fig. 162.)

Time-element Method

This method, as the name implies, depends upon accelerating the motor in a definite time, either a dashpot or motor-operated timing device being used. The connections for starting the motor are the same as for the field frequency method, the difference consisting in the method employed for changing from the starting to the running position. Both methods may use a timing device to permit the field current to build up to its full value at the time of changing over from starting to running.

The difficulty in using a time element for starting a motor is due to the attention required by most time-element devices to keep them in good working order, also the necessity for determining in advance the time required to accelerate the load. A motor ordinarily requires different amounts of time to accelerate its load, depending on the condition of the machinery. If this machinery has been shut down over Sunday it will be cold and the oil in the bearings will be stiff; more time is required to accelerate than when the motor is started up after a short period of rest.

When the time-element device is capable of a wide adjustment, it has the advantage that it can be adapted to any ordinary design of synchronous motor; with the field frequency method, on the other hand, the coil on the lower magnet must be wound to suit the particular motor for which it is used.

COMBINED METHODS

Some large high speed synchronous motors require two starting voltages in order to reduce the kv-a. taken from the line at the time of starting. As pointed out above, the starting torque at a given voltage may be considerably greater than the pull in torque, permitting a relatively low voltage for starting but requiring a higher voltage to pull the rotor into synchronism. The speed at which the controller is changed from the lower to the higher voltage is not important, as the kv-a. input drops down very fast after the motor reaches a considerable speed. The time-element method can be readily used for changing from the starting to the pull in voltage. The field frequency can then be employed for connecting the motor to the line after it has reached synchronous speed.

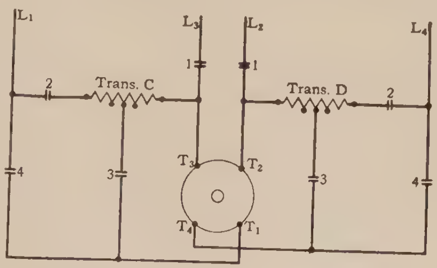


FIG. 162.—Modification of Autotransformer and Main Contactor Connections Required for Control of Two-phase Synchronous Motor

VARIATIONS IN DESIGN OF AUTOMATIC STARTERS

The very wide range of application of the synchronous motor for driving machinery has required variations in the control equipment, such as additional protective or timing relays, phase failure, and phase reversal protection. In central stations electrically operated oil circuit breakers having large current interrupting ability replace the magnet contactors and definite time delay overload and low voltage relays replace the inverse time limit overload relays and instantaneous low voltage relays.

SEQUENCE OF CONTACTOR OPERATION

The autotransformer type of automatic starter may be arranged to close the main contactor and field contactor in different sequence. The usual sequence, previously described, Fig. 160, is as follows:

(1) Close the starting contactors *2* and *3*.

(2) Close the field contactor *FF*, connecting the field to the exciter.

(3) Open the starting contactors *2* and *3* and close the running contactor *4*.

When a greater pull in torque is required, the following sequence is used:

(1) Close the starting contactors *2* and *3*.

(2) Open the starting contactors and close running contactor *4*.

(3) Close the field contactor *FF*.

This sequence gives a higher current peak when the motor is transferred from the starting to the running step.

HIGH VOLTAGE SYNCHRONOUS MOTORS

The use of synchronous motors connected to high voltage power systems requires some additional arrangement of main switching apparatus but the same general types used for induction motor control are applicable. Alternating-current motors of 2200-, 4400- or 6600-volt ratings are automatically started by means of magnetic contactors with oil immersed contacts, or by magnetic contactors equipped with special magnetic blowout devices to interrupt successfully in air the flow of alternating current at high voltage.

The double set of control relays and interlocking features used in the automatic starter, Fig. 160, is applied to the control of high voltage synchronous motors.

In general large slow speed motors are started like the smaller ones. It is essential to use magnetic contactors or circuit breakers having ample current carrying capacity, rugged construction, and the ability to make and break electric circuits through which heavy alternating-currents flow.

Low Line Voltage

Low line voltage interferes with the magnetic contactor performance during starting and increases the time required to accelerate the motor to full speed.

Some automatic starters have a small contactor which short-circuits the motor field rheostat or exciter field rheostat when the motor is being started. This operation overexcites the field, improves the pull in torque, and reduces the current peaks when transferring the motor from starting voltage to full line voltage. When an individual exciter is used to provide the motor field excitation, the added contactor improves the operation of the direct-current contactors by having full exciter voltage impressed on the operating coils while the motor accelerates to full speed.

Line Voltage Automatic Starters

Low speed synchronous motors can be started by connecting them directly to the line. The starting kv-a. with full line voltage approximates three times the normal input kv-a. This value is no higher than required for some of the high speed synchronous motors started with sixty-five per cent of line voltage, which is the standard starting voltage when autotransformers are used. When full line voltage is applied to a motor the starting period is decreased approximately sixty per cent (from one minute to twenty-four seconds).

The line voltage starter in addition subjects a synchronous motor to fewer current peaks than the reduced voltage starter of the type that opens the motor circuit at transfer from starting to full voltage, but the starting kv-a. is higher. High starting kv-a. is of lesser importance on large power systems, but the design limitations of the motor in some cases prohibits starting with full line voltage.

When conditions permit line voltage starting the control equipment is simplified and the number of main contactors or circuit breakers is reduced. One three-pole magnetic contactor or circuit breaker is sufficient to connect the motor directly to the power line. The double set of control relays and the magnetic field contactor is required with either method of starting. The same or the equivalent protection to the operator and equipment should be provided.

MANUALLY OPERATED STARTERS

Many synchronous motors are started with the ordinary autotransformer starters commonly used with squirrel-cage induction motors. Combinations of circuit breakers may also be used for this purpose in conjunction with autotransformers. Usually a combination of circuit breakers is provided with mechanical interlocks to ensure a correct sequence of operation. In order to start a motor manually with the circuit breaker type of starter the following sequence is followed:

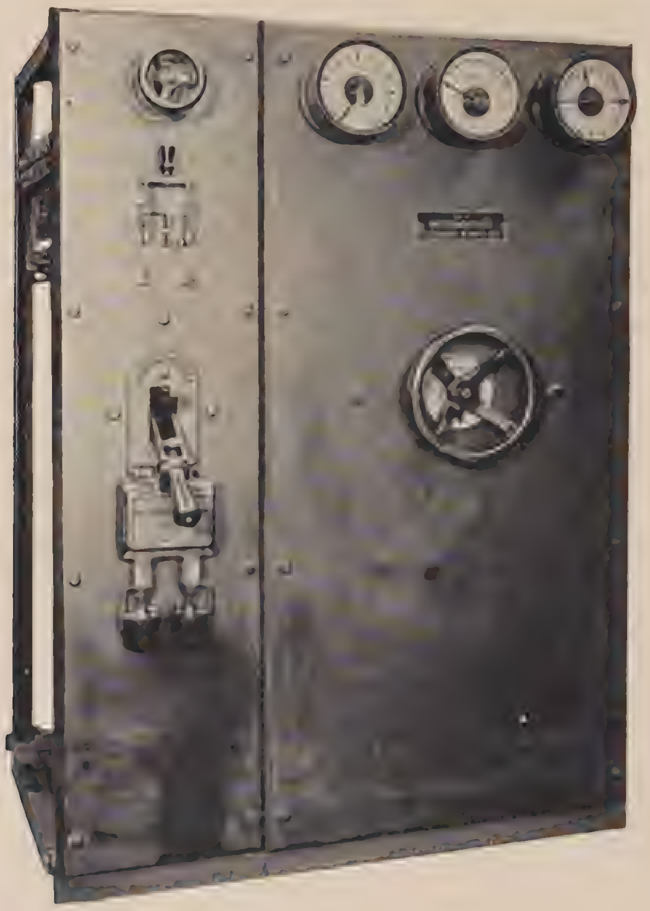


FIG. 163. Manual Starter for 3-Phase 2200-Volt Synchronous Motor

(1) Close the disconnecting switches in the a-c. power circuit.

(2) Throw the field switch to the start position.

(3) Close the starting connections.

(4) Watch the direct-current field ammeter, and when the vibration becomes practically zero the motor is running at synchronous speed. When this occurs the starting connections should be opened and the running connection closed.

(5) The switch in the field circuit should be thrown to the running position and the field rheostat adjusted to obtain the desired power factor.

To stop the motor, the operator

(1) Opens the running connections, disconnecting the motor from the a-c. power circuit.

(2) Opens the field connections, to disconnect the field from the d-c. exciter circuit.

The above sequence of operation can be changed by performing operation *5* prior to operation *4* in starting the motor. This will cause less disturbance to the line but the motor will not develop as much pull in torque as with the sequence given above. It is for this reason that standard controllers usually connect the motor to the line before energizing the field windings. With most controllers this change in sequence can easily be arranged.

Low speed synchronous motors can usually be started by connecting them to the full line voltage by means of a single throw oil circuit breaker. Starters of this kind omit the circuit breakers used to obtain the low starting voltage and also the autotransformers. When the motor has accelerated to approximately synchronous speed as indicated by the field ammeter the operator connects the motor fields to the exciter circuit, which assists in bringing the motor into synchronism.

During the starting period it is necessary to provide means for short-circuiting the overload trip coils, and also any current-indicating instruments that may be used, in order to protect them from the heavy starting current.

EMERGENCY STOP

Certain applications, such as rubber and paper calenders, require means for quickly stopping machinery in case of emergency. One means of accomplishing this is to use a magnetic clutch and magnetic brake. When the emergency occurs the operator actuates the emergency switch which disconnects the motor from the machinery by means of the magnetic clutch; at the same time the brake is applied, bringing the machinery quickly to rest.

Another method consists in the use of dynamic braking. When the operator actuates the emergency switch, the motor is disconnected from the line and the a-c. windings are short-circuited through a resistor. The revolving field magnets generate a voltage in the a-c. windings which causes a heavy current to flow, converting the motor into an a-c. generator and bringing it quickly to rest. Tests have indicated that many designs of motors can be stopped as quickly with dynamic braking as with the use of a clutch and magnet brake. Dynamic braking requires more switching apparatus but eliminates the clutch and magnet brake.

Power Factor Correction

Synchronous motors like synchronous generators can have the field overexcited and deliver a wattless current 90 degrees in advance of the load current. This leading wattless current will neutralize an equivalent amount of lagging current and in this way improve the power factor of any particular installation.

It is this ability to improve the power factor of the given installation that makes it so desirable to use synchronous motors. In order to furnish this leading current it is necessary to build a motor larger than would be required to drive the load and it therefore adds to the expense of the installation to improve the power factor.

If the installation is a factory or other large user of power having a considerable number of induction motors the amount of lagging current which would be necessary to neutralize is considerable. Unless the loads to which the synchronous motors are attached are in large units it may be cheaper to use induction motors for all the mechanical drives and supply one synchronous machine running light, commonly known as "floating" on the system. The entire output of this machine can then be used for power factor correction.

SUMMARY OF CHAPTER XVI

Hunting in synchronous motors, or the tendency to oscillate above and below the synchronous speed, is eliminated by the damper winding, a winding similar to the secondary winding of a squirrel-cage induction motor. This winding gives the synchronous motor a starting torque comparable to that of a squirrel-cage motor of the same number of poles, but as this torque decreases as the motor approaches synchronous speed, the oscillating positive and negative torque produced by exciting the d-c. field is then used to pull the rotor into synchronism. If the field is excited too soon the negative torque periods may hold the motor out of synchronism, but if a direct connected exciter is used the field coils may be connected to the exciter at starting and the exciter voltage allowed to build up from zero, as by this time the period of predominating positive torque will usually be reached.

Synchronous motors may be started by manually operated starters, consisting of a combination of autotransformers and mechanically interlocked circuit breakers. Low speed synchronous motors (preferred to low speed induction motors because of the inherently poor power factor of the latter) may be connected directly to the line, resulting in a higher starting current, but simplifying the control and reducing the time of starting. However, on account of the number of circuits manipulated and care required in synchronizing, automatic starting of synchronous motors is usually preferable.

In automatic starters the abrupt decrease, on reaching synchronous speed, of the alternating-current, induced in the d-c. field coils by transformer action with the rotating a-c. field, is used to operate the devices changing the connections from starting to running (field frequency method); or, a dashpot or motor-operated time-element device may be used (time-element method); or the two methods may be combined.

For starting high voltage synchronous motors, oil circuit breakers or air break contactors with special magnetic blowout devices are used, and for large synchronous motors automatic circuit breakers and definite time delay overload and low voltage relays may replace the contactors and inverse time-element overload and instantaneous low voltage relays.

Where low line voltage is encountered, a contactor to cut out the field rheostat and give a greater pull in torque may be added.

Emergency stopping of rubber or paper calender motors may be accomplished by means of a magnetic clutch and magnetic brake, or dynamic breaking may be used.

A synchronous motor larger than necessary to drive the machinery to which it is applied is frequently provided and used to improve, by over-excitation of the field, the power factor of the consumer's system, or, in large factories, induction motors may be installed and a single synchronous machine floated on the system for power factor correction alone.

CHAPTER XVII

RESISTORS[1]

Cast iron grid type of resistor—embedded (tube or plate) type—graphite compression type—heat absorption versus heat radiation—rating depends upon intermittency of service—how spacing affects radiation—speed regulating rheostats (1) for constant torque duty, (2) for fan duty—intermittent (crane) duty resistors (1) for general purpose duty, (2) for heavy duty—"time on out of four minute" classification—how to design resistors—tapering capacities—arrangement in frames.

THE most common form of resistor is the cast-iron grid, shown in Figs. 164 and 165. Cast iron is admirably adapted for this purpose on account of its cheapness, high electrical resistance, freedom from corrosion, and small temperature coefficient. The resistance of cast iron increases about 15 per cent with a change of temperature of about 250 degrees. Its principal limitation is that it is not suitable for small apparatus where a large ohmic value is required with a small capacity, requiring high resistance units of small size.

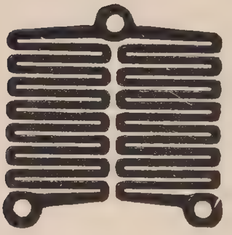


FIG. 164. Cast-iron Grid Resistor Unit

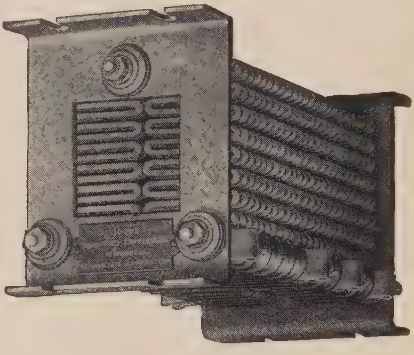


FIG. 165. Grid Resistor

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[1] The Electric Power Club defines a "resistor" as: "An aggregation of one or more units possessing the property of resistance, used in an electric circuit for the purpose of operation, protection or control of that circuit." This term was coined to express properly the part of a controller often referred to as the "resistance." The word "resistance" expresses the property of a substance and should not be used to denote the material itself.

Where a large ohmic value is required in a small space the embedded type resistor is used. It is made in various forms, the resistance material usually consisting of a wire or ribbon embedded in enamel or some similar compound, as in Fig. 167. It is also common to make up units in the form of plates. Embedding the resistance material gives increased thermal capacity and mechanical protection. It also prevents conducting material, such as metal dust, from collecting on the unit and reducing the resistance. Most of these embedded units can be heated to destruction without any external flash or drippings.

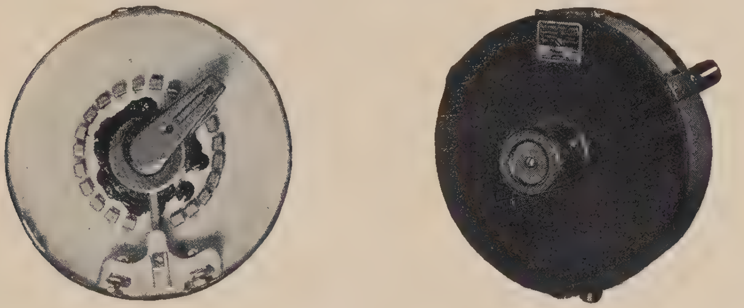

FIG. 166

Cast iron grids are placed on insulating rods and mounted between end frames, thus forming convenient units. Where it is desirable to combine the cast iron grids with an embedded type of resistor, either the embedded resistor should be in the form of a plate or the tubes should be mounted so that they will fit in the same frame with the grids.

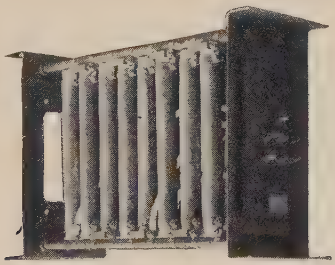

FIG. 167. Embedded Type Tubular Resistor

Some rheostats and controllers have resistors composed of graphite discs. The change in ohms is obtained by changing the pressure on the column of discs. These discs are illustrated in Fig. 168 and a rheostat of this type in Fig. 169. The change in ohms with pressure is shown in curve, Fig. 170. If a rheostat were designed so that the pressure on the

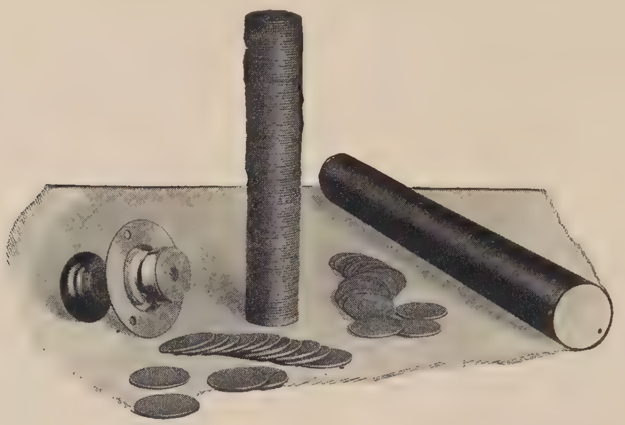

FIG. 168. Column of Discs Used in a Graphite Disc Resistor

column was changed in a uniform manner the resistance would not be altered so as to give the best starting or regulating conditions. In order to improve this condition a cam is used for compressing the resistance column. This cam acts through a spring and is so designed that equal movements of the controller handle give approximately equal changes in resistance. The curve in Fig. 170 shows the change in resistance with the movements of the controller handle. Controllers using this form of resistor are shown in Figs. 106, 107 and 108.

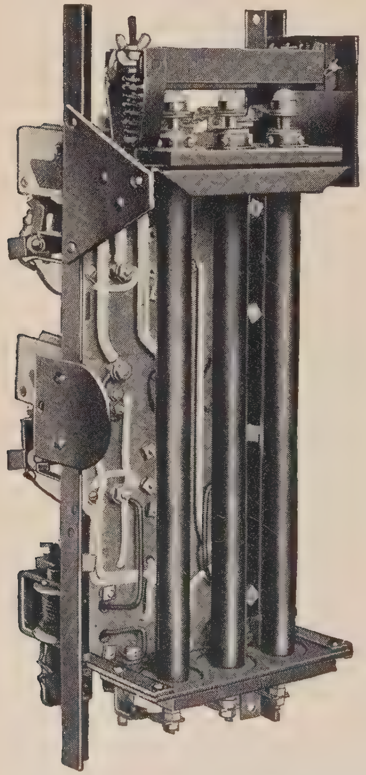

FIG. 169. Graphite Disc Type Speed Regulator for Slip-ring Motors

A "rheostat" is defined by The Electric Power Club as a resistor provided with means for varying its resistance. This usually takes the form of a series of contacts mounted on the surface of an insulating material having an arm arranged for making connection between a central post, which forms the pivot of the arm, and the various contacts which are arrange in a circle. Mounted back of this face plate is a series of resistor units, as shown in Fig. 173. For small sizes, the contacts and resistance material are both embedded in a compound forming a complete unit, known as a plate-type rheostat.

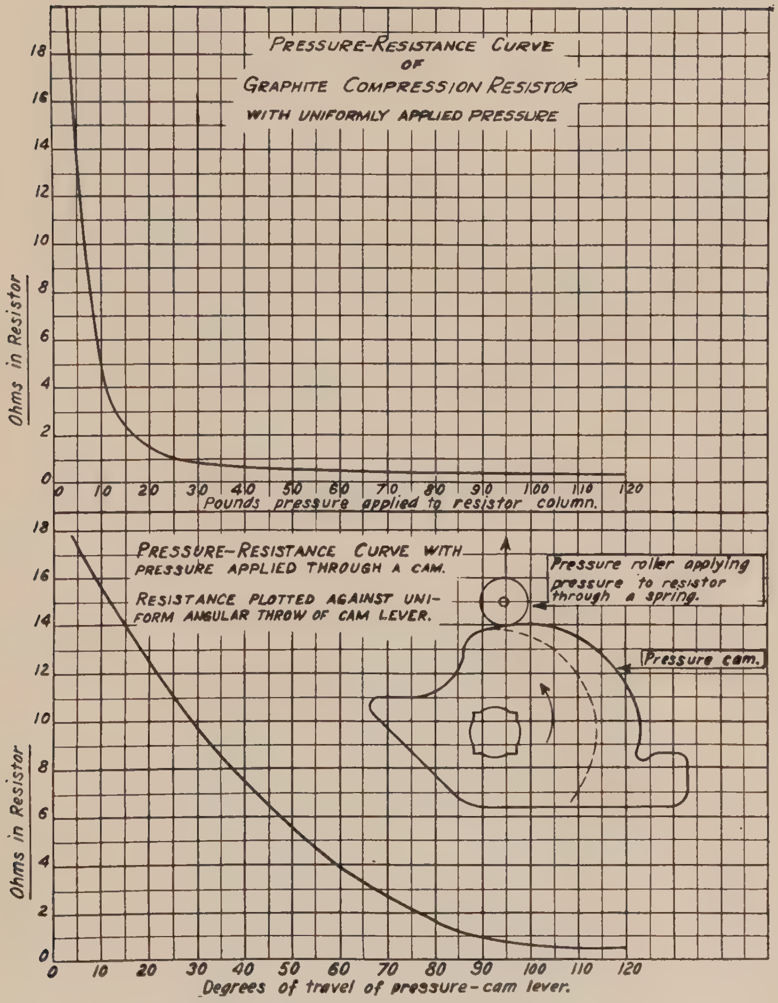

FIG. 170. Pressure-resistance Curve of Graphite Compression Resistor

FIG. 170. This curve shows the relation between the resistance of the carbon pile and a uniformly increased pressure applied to the column. When used in apparatus requiring a uniform decrease in resistance with a uniform travel of the controlling lever, the increments of pressure should not be uniform, but should be carried through suitable cams and springs as shown in the lower curve

In applying resistors, two points should be considered: (1) The ability to radiate or conduct the heat from the unit to the surrounding atmosphere, (2) the ability to absorb heat. Usually the mass of the resistor is small compared with that of a motor or controller for dissipating the

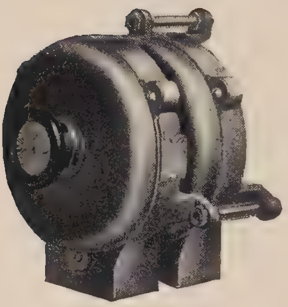

FIG. 171. Two 6-in. Plates

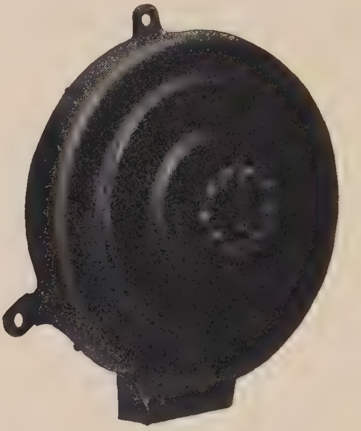

FIG. 172. One 12-in. Plate

Plate Type Rheostats for Conduit Wiring

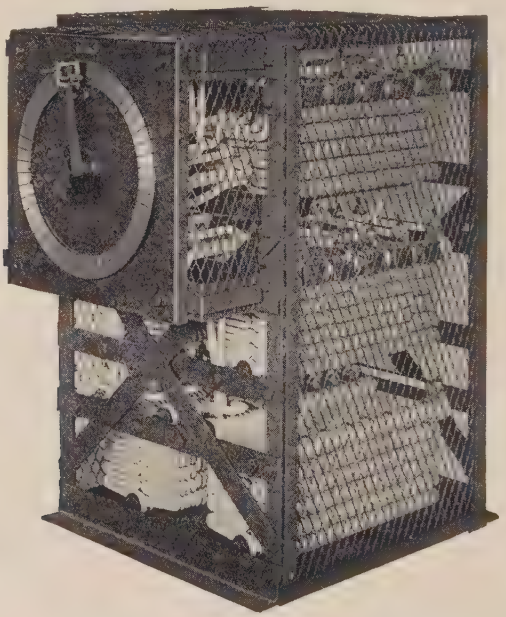

FIG. 173. Rheostat Made up of Grid Resistors, Showing Series of Contacts on Face Plate

same amount of heat energy, so that the energy absorbed by the resistor will raise its temperature more rapidly. When the resistor is used for starting purposes only, the absorption forms a very important item in the design. For intermittent duty, radiation is the controlling feature. The relation between temperature rise in degrees C. and the watts per unit for five different conditions of operation is shown in Fig. 176. The heavy line is the average value and the dotted lines on either side represent the variations due to the different cross-sections of the grids used. These curves, of course, apply only to one particular size of grid and are shown for the purpose of illustrating the effect which different classes of service have upon the capacity of a resistor of a given size. Curve *1* is for continuous service; Curve *2* for a cycle of duty, in which the re-

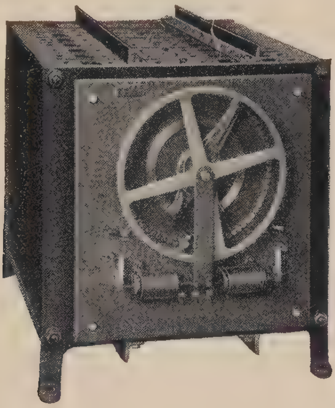

FIG. 174. Electrically Operated Tube Type Rheostat

The electrically operated field rheostats are provided with a rachet-driven switch for electrical operation. The ratchet-operating coils are usually wound for 125 volts direct current, but can be wound for any other direct-current circuit up to 600 volts.

DISTINCTIVE FEATURES

(1) Switch arm carried around by pawls which engage knurled rim of the wheel to which the switch arm is fastened.

(2) Solenoids energized by single-pole, double-throw switch. The left solenoid, when energized, operates the switch arm in a clockwise rotation, cutting in resistance. The right solenoid, when energized, operates the switch arm in a counter-clockwise rotation, cutting out resistance.

(3) Each end of switch dial provided with a limit switch which, automatically operated by switch arm, opens the circuit of the solenoid when resistance is entirely cut in or out. Mechanism thereby protected in case control circuit is left closed when the dial switch has reached its extreme point of travel in either direction.

(4) Possible to locate these rheostats in any part of the station to control the generator voltage by the use of a single-pole, double-throw switch on the panel.

sistor is in circuit for two minutes out of every four, with two minutes' rest between. Curve *3* represents a duty cycle of an ordinary shop crane of one minute service and three of rest. Curve *4* represents a duty of 30 seconds with 3.5 minutes of rest. Curve *5* is a duty of 15 seconds in each four minutes. Curve *5* corresponds to ordinary starting duty. In making these tests, it was found that the spacing between the grids was an important factor and preliminary tests were made to determine the most economical spacing. Similar data should be obtained for any form of resistor used, so that an intelligent application can be made.

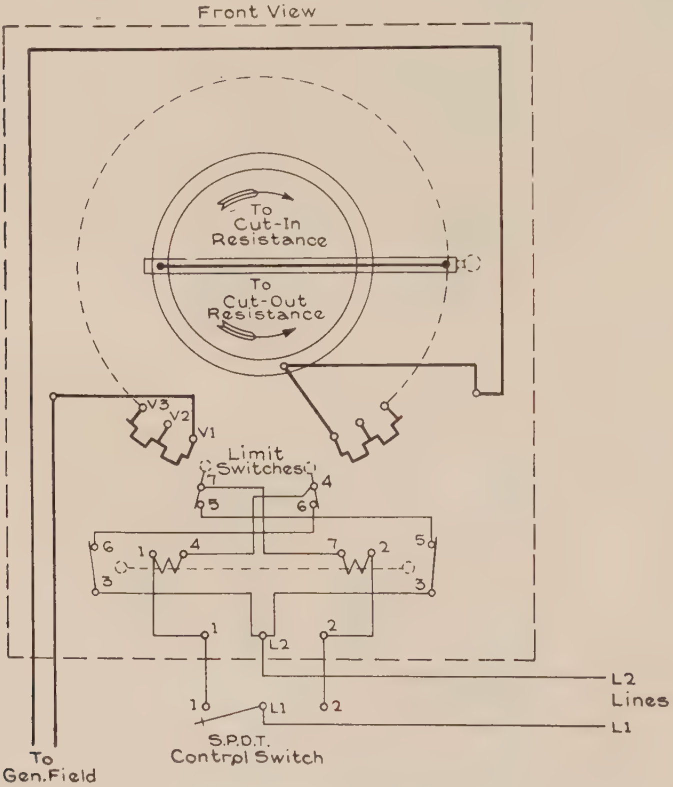

FIG. 175. Connections for the Ratchet Mechanism of the Rheostat Shown in Fig. 174

The effect which the spacing of the grids has upon their radiating capacity is shown in Fig. 181. Standard grids were used and the spacing between the grids was changed by introducing washers. Curve *a* shows the minimum spacing. Curve *b* shows the effect of increasing this spacing by one-fourth inch. Curve *c* shows the effect of increasing it by three-eighths inch. Further tests were made by increasing the spacing one-half inch, but the results were practically the same as with the three-

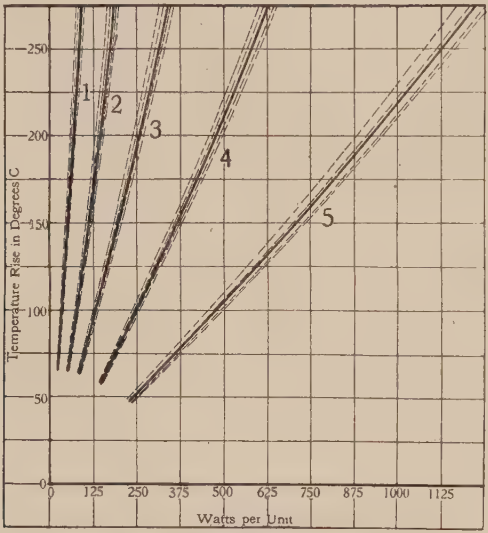

FIG. 176. Relation of Temperature Rise and Energy Loss per Resistor Unit for Five Different Classes of Service

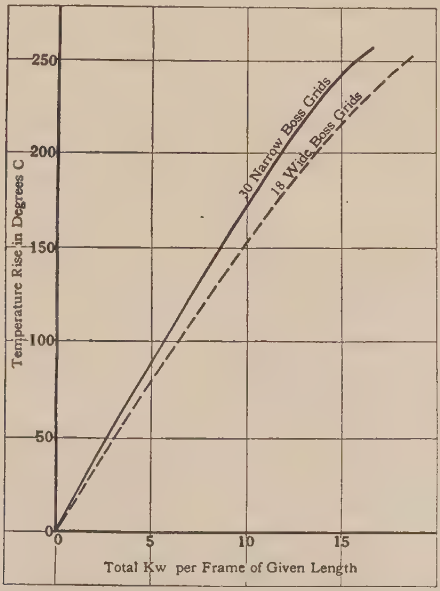

FIG. 177. Comparative Radiating Capacity of the Same Size Resistor Frame Using Different Spacings of Grids

eighths inch increased spacing, showing that the economical limit had been reached for that particular design. The curves show very clearly the increase in capacity with a rise in temperature. Where the grids are spaced close together the increase in capacity per degree rise of temperature is less than for the wider spacing. The tests show that if the resistor is used for continuous or intermittent duty, considerable material can be saved by a proper spacing of the grids.

The economical arrangement of the grids is more clearly shown in Fig. 177. The duty cycle corresponds to Class No. 50, Table V. The solid line curve was obtained from a frame of 30 grids with narrow bosses, and the dotted line curve from a frame of 18 grids with wide bosses. The frame was the same length in both cases. The curves indicate that the frame of wide boss grids radiated more energy than the one with narrow boss grids. It is therefore a better frame, costs less, and is lighter in weight. The same relation could be shown if similar curves were plotted for heavy starting duty and heavy intermittent duty.

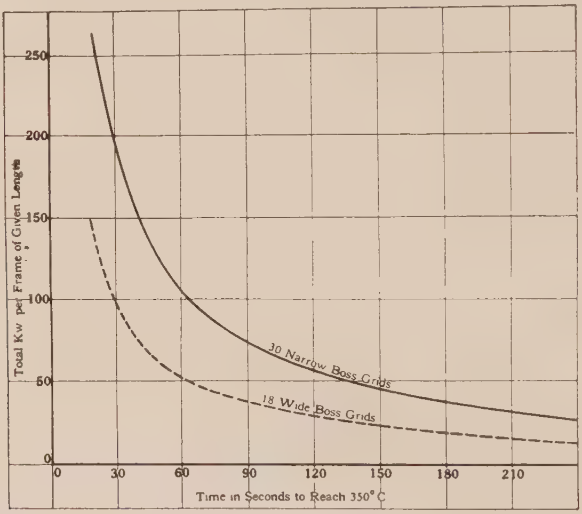

FIG. 178. Comparative Heat Absorption of Two Resistor Frames of the Same Length Having Different Number of Grids

The same grid frames were used as illustrated in Fig. 177

For light starting duty the time cycle is so short that most of the energy is absorbed by the resistor material itself, and radiation has less effect. Therefore, the grids for this duty are spaced much closer together and the capacity is determined largely by the weight of the material and less by the radiation. From a heat absorption standpoint, for light starting duty the narrow boss grids are better, as shown in Fig. 178.

In designing resistors certain arbitrary assumptions must be made, as it is manifestly impossible to predetermine the exact cycle of operation for many applications. The National Board of Fire Underwriters several years ago adopted tests for starting rheostats which have proved very satisfactory for general purpose starters. They are based on the average operating conditions which must be met when the motor is started, and provide a sufficient factor of safety to give protection against fire hazard. Where the rheostat is used for speed regulation, its design is a simple matter if the load is known. Ordinarily, the requirements may be grouped as to duty into two classes, one known as "constant torque," where it is assumed that the current remains practically constant throughout the entire speed range and is equivalent to the full-load motor current; and another known as "fan" duty, where it is assumed that the current is approximately proportional to the speed of the motor.

The more difficult applications are for intermittent duty such as crane service. The general purpose crane used in an ordinary machine shop

TABLE V

RESISTOR CLASSIFICATION TABLE

Adopted by the Electric Power Club

Per cent Full Load Current on First Point	Starting Torque in Per cent of Full Load *				Resistor Class Number				
					Starting duty		Speed regulation		
							Intermittent duty		Continuous duty
	Series motors	Compound motors	Shunt motors	Wound rotor induction motors	Light, 15 seconds on out of 4 minutes	Heavy, 30 seconds on out of 4 minutes	Light, 1 minute on out of 4 minutes	Heavy, 2 minutes on out of 4 minutes	
25	8	12	25	....	11	31	51	71	91
50	30	40	50	30	12	32	52	72	92
70	50	60	70	50	13	33	53	73	93
100	100	100	100	100	14	34	54	74	94
150	170	160	150	150	15	35	55	75	95
200	250	230	200	200	16	36	56	76	96

* Compound wound motors are based on 30 per cent series winding.

or foundry operates over a wide range of load and for varying intervals of time. An early analysis of this problem caused manufacturers to rate their resistors on the basis of different loads for different time intervals, assuming that if a heavy load were being lifted it would occur seldom and the time interval, therefore, could be made relatively short. The same resistor could be used for an average load operating for a longer period, etc. This method of rating became quite complicated and did not prove practical. An accumulation of data indicates that resistors for crane duty may be divided into two classes: those for "general purpose" duty, and those for "heavy duty," such as in certain operations in steel mills.

Other applications may be similarly analyzed. In order to make it easy to express resistors in a definite way, the Electric Power Club adopted the resistor classification shown in Table V, to which has been added the torque for various standard motors. The horizontal lines classify the resistors according to the percentage of full-load motor current that is obtained when all of the resistor is in the circuit, and the vertical lines represent the service conditions.

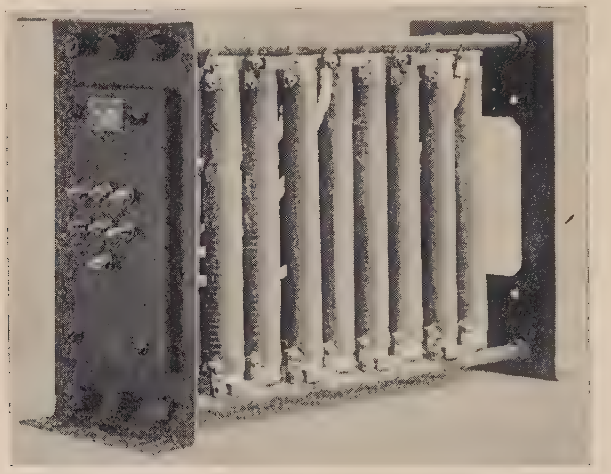

FIG. 179. Resistor of Wire Coils Wound Around Insulated Tubes

The period of four minutes is assumed because tests indicate that the average resistor will approach its limiting temperature if left in the circuit for four minutes. In designing resistors to meet the classifications shown in this table, the Electric Power Club agreed that the limiting temperature rise for resistors should not exceed 350 degrees C. when the thermometer can be placed against the resistive conductor, and 250 degrees C. when the thermometer is placed against the embedding material. They also agreed that the limiting observable temperature rise for the air issuing from the resistor enclosure shall not exceed 175 degrees C. when the thermometer is placed one inch from the enclosure.

The starting and intermittent duty resistors in the classification table are primarily designed for use with motors requiring an initial torque corresponding to the current value for the class of resistor specified and requiring a root mean square accelerating current not more than 125 per cent of the full-load motor current.

If the resistor is tested without connecting it to a motor, it should be connected to a line voltage that will give the initial current specified, and the steps should be cut out at equal intervals in the "time on" period. Of the cycle specified, the current at no time during the cutting out period should exceed 125 per cent of the rated value. This test should be repeated every four minutes and continued for one hour. If resistors are desired for a longer time period than that shown in Table V, the next higher class number to the right should be selected; if a higher starting torque is required, select the next larger class number in the vertical column.

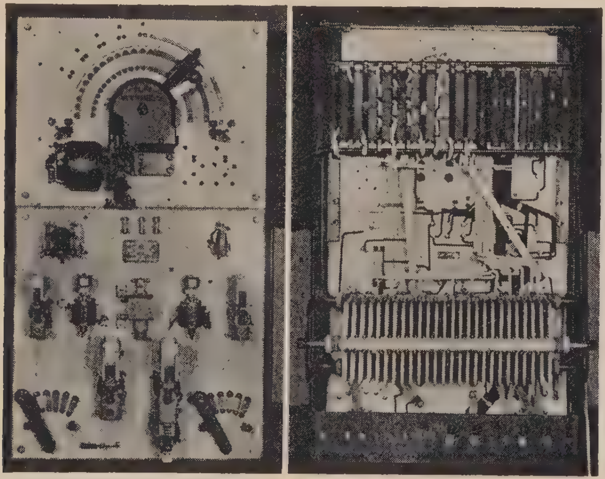

FIG. 180. Method of Mounting Tube and Grid Resistors on Control Panel

The different resistor classifications may be summarized briefly as follows:

Light Starting Duty resistors are intended to be in circuit not over 15 seconds at any one time, and not oftener than once every four minutes.

Heavy Starting Duty resistors are intended to be in circuit not over 30 seconds at any one time, and not oftener than once every four minutes.

Light Intermittent Duty resistors are intended to be in circuit not more than one minute in every four-minute period. They are intended for applications such as cranes, where the load is thrown on and off frequently.

Heavy Intermittent Duty resistors are intended to be in the circuit not over 2 minutes out of every four-minute period. This resistor is equivalent to a half time rating and is used for hoisting and other applications requiring intermittent regulation.

Speed Regulating Resistors for Continuous Duty are intended to be in circuit an indefinite period of time.

The amount of speed reduction obtained with a resistor in series with the armature, or in the secondary of a slip-ring motor depends upon the load on the motor, and may be obtained from the following formula:

$$\begin{array}{c}\text{Speed reduction obtainable}\\ \text{in per cent of full}\\ \text{load speed}\end{array} = \frac{\begin{array}{c}\text{Actual load torque}\\ \text{required in per cent}\\ \text{of full load}\end{array}}{\begin{array}{c}\text{Torque given in column}\\ \text{under particular}\\ \text{motor used}\end{array}} \times 100$$

For example, consider a wound rotor motor with Class 95 resistor connected to a load requiring 70 per cent torque at slowest speed; this will give a speed reduction of $\frac{70}{150} \times 100$ or 47 per cent.

The current taken from the line during the starting period is less than would be obtained by dividing the effective voltage by the ohms resistance. This reduction in current is caused by the inductive effect and the resistance in the lead wires and motor circuit. For the average application, the peak current during acceleration can be assumed as approximately two-thirds of the calculated value.

It is found in practice that the results obtained by different engineers agree very closely, so that the product of different manufacturing companies is on the same basis. The ordinary method of procedure is to divide the resistor into steps which follow a geometric progression. This can be worked out and tabulated for quick reference, as shown in Table VI.

The method of calculating the ohms per step in a given resistance takes the form of a geometric series, —$R + RX_1 + RX_2 + RX_3$, *etc.*, where R is the internal resistance of the motor and controller and X is the ratio of maximum and minimum accelerating current. The derivation of this formula can be obtained from text-books on the subject or electrical hand books. The values obtained from such a formula are based entirely upon Ohm's law and do not take into account the effect of inductance in the circuit. It is sufficiently accurate, however, for most calculations.

The total number of ohms in a resistor is fixed by the classification number and the full-load current of the motor, and the number of sections of a resistor is determined by the steps on the controller, so that a designer can refer to the table, using the line corresponding to the steps in the resistor he wishes to design, and then divide the resistor by taking the proper percentage for each step as indicated by the table. This results in a uniform product being obtained with respect to the total ohms in the resistor, and its subdivision into steps.

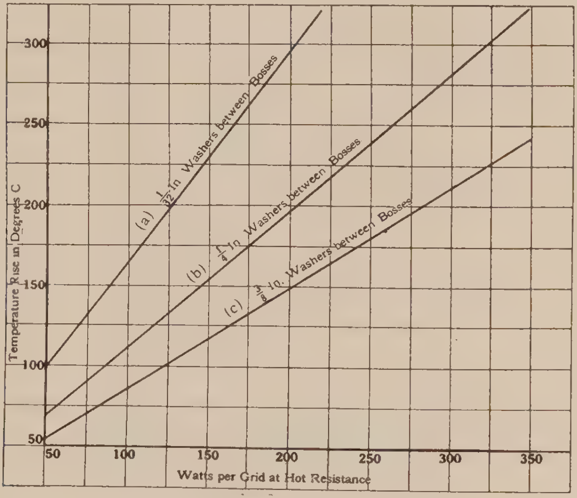

Fig. 181. Relation between the Spacing of Cast Iron Grids and Temperature Rise

It is more difficult to determine the capacity for each resistor step. Data for this part of the design must be obtained from actual tests. A resistor radiates heat in proportion to the fourth power of its absolute temperature (Fig. 183). This means that an increase in the hot spot temperature from 350 to 450 degrees C. will materially increase the heat dissipating ability of the resistor and therefore increase the factor of safety. Cast iron grids show a dull red heat at 600 degrees C., which ordinarily will not damage the grids.

Unfortunately this direct relation between temperature and radiating capacity is materially affected by the method of mounting and the circulation of the cooling air. If one cast iron grid were located where there is a free circulation of air, this law would be followed very closely, but as ordinarily manufactured, cast iron grids are assembled in frames of from

20 to 30 grids. These frames in turn are mounted in boxes with several other frames so that the ultimate radiating capacity of the entire resistor depends upon the complete design.

The effect of increasing the time a grid resistor is in circuit is shown in Fig. 184. This curve was obtained by applying a definite load to the resistor for the time interval corresponding to each classification given in the table. The values plotted were the average hot spot temperatures obtained. The actual temperature on test would first increase while the load was applied and then decrease during the off period. At first this difference in temperature was quite marked, but after the test was continued for one hour only a small variation was observed between the maximum and minimum temperatures, the average of which, therefore, was considered as representing the actual temperature of the resistor for that class of service. A number of tests had to be made to determine the amount of energy which would correspond to a 250 degree C. rise for each duty cycle. The curve shows that a resistor that has a continuous capacity of 240 watts will have 475 watts capacity on heavy intermittent duty, and still higher values for the other classifications.

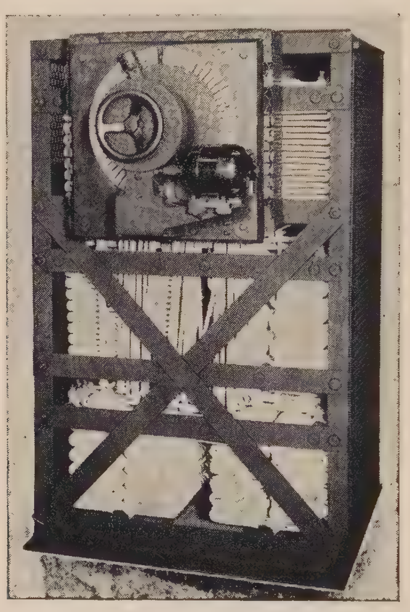

FIG. 182. Cast Iron Grid Resistor with Motor Operated Face Plate

Unused with large generators and operated from remote control switchboard

With test data of this kind available a curve can be plotted as in Fig. 185, showing the relation between the time in seconds, which the resistor

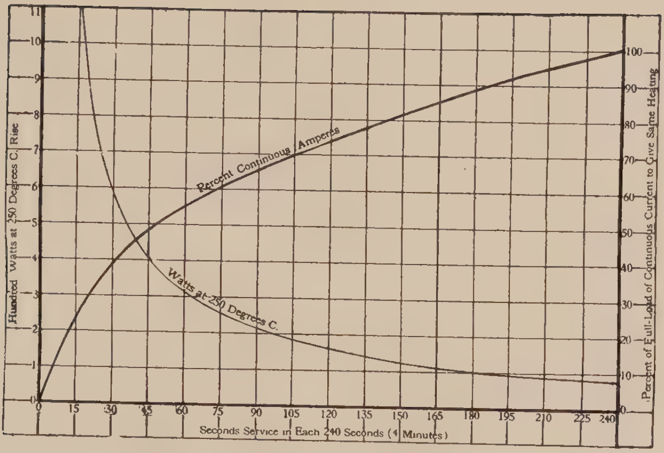

FIG. 183. Energy That Can Be Dissipated in a Grid for Different Lengths of Service

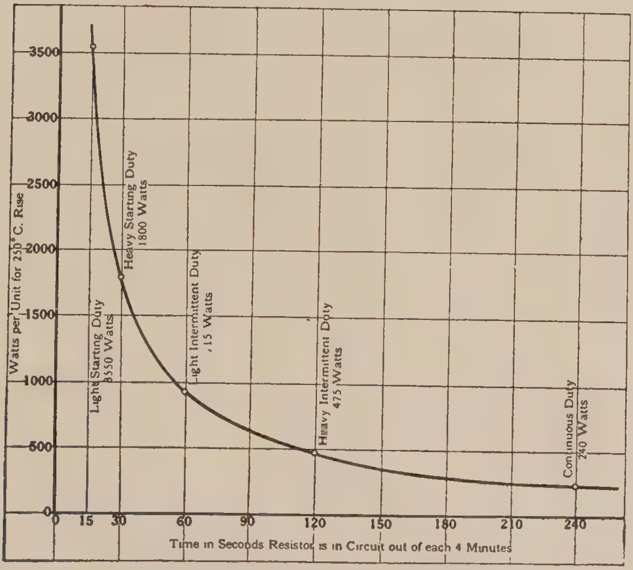

FIG. 184. Relation between Time and Load Required on Grid Resistor to Reach 250 Degrees C. Rise

This curve shows that a given resistor unit having a continuous capacity of 240 watts is good for 475 watts for heavy intermittent duty, 915 watts for light intermittent duty, 1800 watts for heavy starting duty and 3550 watts for light starting duty is in circuit out of each four-minute period, and the percentage of continuous current to give equivalent heating. This last curve forms the basis of an actual resistor design. In Table VI for each number of resistor steps two values are given. One value is the percentage of total ohms in each step; the other is the percentage of full-load current that each step will carry continuously. In designing resistors, it is assumed that the first step of starting and intermittent duty resistors will be in circuit a less number of seconds than the last step. This gives a tapered capacity, so that the percentage of full load which the grid is capable of carrying should be smallest on the first step and increase with each step up to the last. It will be noted from Table VI that on the first step the current is 29 per cent of the full-load current, and on the last step from 43 to 51 per cent, the intermediate steps being tapered between these values.

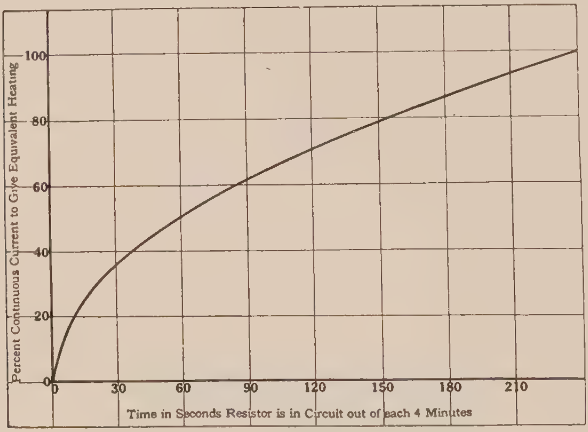

FIG. 185. Relation between Continuous and Intermittent Duty for Various Time Cycles

Values are plotted for one particular size of resistor and are based on a temperature rise of 250 degrees C.

All of the foregoing data were taken from one particular design and are not applicable to any other design. They are given because they show clearly the relation that exists between the temperature of the grid and the current passing through the grid for different conditions, and serve to illustrate how the design problem is worked out in practice. A different table is required for each size and type of resistor unit, and a different table for each resistor classification. For each ohmic value of grid of the same design it will be found that there is a slight variation in the watts per unit between the high and low ohmic values, but this difference is not very great and it is sufficiently accurate to use an average value.

TABLE VI

Methods of Proportioning Resistor Units

Class 35 D.C. and Three-Phase; and Class 34 Single-Phase.

	Number of Steps	Step								
		1	2	3	4	5	6	7	8	9
Per cent ohms..........	1	100								
Per cent full load amps..		44								
Per cent ohms..........	2	72	28							
Per cent full load amps..		29	51							
Per cent ohms..........	3	55	30	15						
Per cent full load amps..		29	40	47						
Per cent ohms..........	4	45	28	17	10					
Per cent full load amps..		29	35	41	45					
Per cent ohms..........	5	37	26	17	12	8				
Per cent full load amps..		29	34	38	42	44				
Per cent ohms..........	6	32	24	17	12	9	6			
Per cent full load amps..		29	34	36	39	42	44			
Per cent ohms..........	7	28	21	16	13	9.5	7	6.5		
Per cent full load amps..		29	34	35	38	40	42	43		
Per cent ohms..........	8	25	20	15	12	9.5	7.5	6.5	4.5	
Per cent full load amps..		29	33	34	37	39	40	42	43	
Per cent ohms..........	9	23	18	15	12	9	8	6	5	4
Per cent full load amps..		29	33	34	36	38	40	41	42	43

As previously explained, the arrangement of the units in the resistor box or frame is determined by test. This also applies to the grouping of resistor frames; i.e., for light starting duty the resistors can be grouped close together, but for intermittent and continuous duty a greater space is required. The total energy dissipated in starting small motors is not great and the arrangement of the frames is simple. Where large motors are used it is desirable not to stack the resistor frames more than three high and considerable space should be left between tiers of frames. Care

TABLE VII

Application of Control Resistors to Specific Industries

Application	Resistor Class Number for Average Conditions	
	Manual Controllers	Magnetic Contactor Controllers
Blowers		
Constant Pressure	a35 or 96	a35 or 96
Centrifugal	34 or 93V	34 or 93V
Brick Plants		
Augers	b35	b35
Dry Pans	b35	b35
Pug Mills	b35	b35
By-Product Coke Plants		
Air Valve Reversing Machines	14	14
Coke Leveler Rams	74	74P
Coke Pusher Bars	74	74P
Door Machines	13	13
Gas Cock Reversing Machines	14	14
Tar Pumps	36	36
Car Dumpers—See Steel Mills		
Cement Mills		
Conveyors—Belt	35	35
Conveyors—Screw	35	35
Crushers—Gyratory	35	35
Crushers—Jaw	35	35
Dryers—Rotary	1	1
Buckets—Elevators	33	35
Grinders	35	35
Kilns	35	35
Pulverizers—Tube Mills, etc.	35	35
Coal Mines		
Breaker Line Shaft	a54 or 95	a54 or 95
Conveyors	54	54
Elevators	33	35
Machine Tools		
Boring Mills	35	35
Bull Dozers	35	35
Drills	35	35
Gear Cutters	35	35
Grinders	35	35
Hobbing Machines	35	35
Lathes	35	35
Milling Machines	g35	g35
Planers	h35	h35
Presses	35	35
Punchers	35	35
Saws	35	35
Shapers	35	35
Metal Mining		
Ball Mills	35	35
Car Dumpers—Mine Type	74	74
Compressors—See Compressors	....	....
Converters—Copper	53	55
Conveyors	35	35
Crushers—Disc	35	35
Crushers—Gyratory	35	35
Crushers—Jaw	35	35
Harding Mills	35	35
Marcy Mills	35	35
Slag Car Tilting	53	53
Tilting Furnace	53	53
Tube Mills	35	35
Metal Working		
Bull Dozers	36	36
Accumulators	....	36
Draw Bench	....	75
Charging Machines		
Bridge	74	74
Peel Revolving	74	74
Trolley	73	73
Coiling Machines	35	35
Conveyors	54	54
Converters—Metal	74	74
Cooling Beds	54	54P
Cranes		
Bridge	54	54P
Hoist	k72 or 72D	k72 or 72D
Stripper	74	74P
Trolley	53	54P
Crushers	35	35
Furnaces—Annealing	74	54P
Furnace Doors	74	54P
Gas Valves	54	54P
Gas Washers	13	13
Hot Metal Mixers	74	74
Ingot Buggy	54P	54P
Kick Off	54P	54P
Levelers	74P	74P
Manipulator Fingers	74P	74P
Manipulator Side Guard	74P	74P
Metal Mixers—Hot	74P	74P
Ore Unloaders		
Apron Hoist	k74 or 72D	k74 or 72D
Bridge	m74	m74
Elevator	74	74
Hoist	k73 or 72D	k73 or 72D
Trolley	m74	m74
Pickling Machines	54	54
Pilers—Slab	54	54

Fans—Mine	a34 or 93V	a34 or 93V
Haulages—Tail Rope	72	72
Hoists—Slope	72	72
Hoists—Vertical	73	73
Jigs	35	35
Pickers—Rock and Slate	35	35
Repair Shop	35	35
Rollers	35	35
Shaker Screens	a35 or 95	35
Compressors		
Constant Speed	c35	c35
Varying Speed	d95	d95
Concrete Mixers	35	35
Conveyors—Belt	33	35
Conveyors—Screw	35	35
Cranes—Foundry		
Bridge	53	54
Hoist	e53 or 52D	e53 or 52D
Trolley	53	53
General Service	....	....
(Machine Shop)	....	....
Bridge	53	54
Hoist	e53 or 52D	d53 or 52D
Trolley	53	53
Hot Metal } See		
Stripper } Steel		
Skull Cracker } Mills		
Flour Mills		
Line Shafting	35	35
Hoists		
Slope—Balanced	72	72
Slope—Unbalanced	72	72
Vertical—Balanced	73	73
Vertical—Unbalanced	75	75
Winch	52	53
Lift Bridges	53	53
Machine Tools		
Bending Rolls—Non-Reversing	34	34
Bending Rolls—Reversing	54	54
Ore Bridges		
Rack	74	74
Rail Clamp	92	92
Trolley	74	74
Hoist	i74 or 72D	i74 or 72D
Paper Mills		
Beaters	35	35
Calenders	54	54
Grinders	35	35
Paper Machines	Voltage	Control
Pipe Working		
Cutting and Threading	35	35
Expanding and Flanging	a35 or 95	a35 or 95
Pumps		
Centrifugal	a34 or 93V	a34 or 93V
Plunger	a35 or 95	a35 or 95
Rubber Mills		
Calenders	....	....
Crackers	35	35
Mixing Mills	35	35
Washers	35	35
Swing Bridges	53	53
Shovels		
Hoist	73	73
Swing	73	73
Thrust	93	93
Steel Mills		
Accumulators	35	35
Bar Pullers (Pipe Mills)	54	54
Bucket Hoist		
Hoist	72D	72D
Shell Line	72D	72D
Trolley	74	74
Bridge	74	74
Bull Dozer	55	55
Car Dumpers	52	52
Barney or Mule Haul	52	52
Cradle Hoist	k74 or 72D	k74 or 72D
Hoist	35	35
Casting Machines—Pig	35	36
Pipe Cutting and Threading Machines	n35	n35
Racks	54	54
Reelers	35	35
Saws—Cold	55	55
Saws—Hot	55	55
Screw Downs	74	76
Shears	55	55
Shuffle Bars	54	54P
Sizing Rolls	54	54P
Skull Cracker Crane	54	54
Slab Buggy	54	54P
Soaking Pit Covers	54	54P
Straighteners	54	54P
Straightening Rolls	54	54P
Tables—Lift	54	56
Tables—Roll	54	54P
Tables—Transfer	54	54P
Tilting Furnaces	54	54P
Wire Stranding Machine	35	35
Stokers—Underfeed	93V	93V
Wood Working Plants		
Boring Machines	35	35
Lathe	35	35
Mortiser	35	35
Moulder	35	35
Planers—Surface	35	35
Planers—Jointer	35	35
Power Trimmer and Mitre	35	35
Sanders—Disc	35	35
Sanders—Multiple Drum	35	35
Sanders—Single Drum	35	35
Saws—Band	35	35
Saws—Band Resaw	35	35
Saws—Circular	35	35
Saws—Cross Cut	35	35
Saws—Jig	35	35
Saws—Rip	35	35
Shapers	35	35
Shingle Machines	35	35

The letter D added to 50 or 70 classes indicates additional capacity for dynamic braking while lowering.

The letter P added to 50 or 70 classes indicates additional capacity for plugging service.

The letter V added to class 93 indicates resistor for variable torque application.

a Lowest class for starting and highest for speed control.

b 55 used where clay is extra stiff.

c If started unloaded use resistance of 1/3 H. P. For example if for 30 H. P. use 10 H. P. resistors.

d If started unloaded, order Class 93 resistor.

e Use 52-D for dynamic braking while lowering or when crane does not have load brake.

f 35 used for constant speed; 95 used for varying speed.

g Applies to non-reversing. For reversing use Class 75.

h 56 used in exceptionally cold localities.

i Use 72-D for dynamic braking while lowering or where crane does not have load brake.

k Use sub-letter D for dynamic breaking while lowering or where crane does not have load brake.

m If for plugging service specify 74P.

n If for plugging service specify 54.

should be taken to insure a free circulation of air around all of the resistor frames. Their capacity will be materially limited if they are located in the corner of a room or protected by partitions in such a way that the circulation of air is restricted. In arranging the grids in tiers the frames should be located in such a way that the heat will be distributed equally among the tiers.

Each application for controllers must be studied and the classification of resistor selected after operating data are obtained. The same classification of resistor may not be equally well adapted for the same type of service in different mills and industrial establishments. It is, therefore, difficult to give a definite classification for every application.

Table VII is believed to represent the average conditions in the industry. It is given in the hope that engineers who have charge of electrical equipment will carefully observe the performance of the resistors and check the data given in this table. It is only by a process of trial and elimination that application information of this kind can be built up.

Any engineer having occasion to select control equipment for a particular application realizes the importance of such data. The manufacturer of the control equipment may not have actual test data available for the particular application and, therefore, must use the average data in his possession. The more generally these data are used, the more nearly will the table represent average conditions. With these average conditions and their probable limits of error known the application of resistors from the classification table will be made relatively simple and both manufacturer and user will be benefited. Any engineer having difficulty with resistors on a particular application and finding that he has selected the correct classification may then examine this particular application with a view to determining in what way it differs from the normal.

SUMMARY OF CHAPTER XVII

For resistors cast iron grids, because of their cheapness, high electrical resistance, and small temperature coefficient (15 per cent change for 250° C.), are used when possible, but when a high resistance unit in small space is required an embedded type resistor, such as an enameled wire wound tube, is used, the embedding material giving greater thermal capacity and mechanical protection. Another form, the graphite disc compression type of resistor, is made up of columns of graphite discs, different values of resistance being obtained by varying the pressure on the columns. A resistor combined with means for varying its resistance is termed a rheostat.

Tests on cast iron grids show that

(1) for intermittent duty heat absorption,

(2) for continuous duty heat radiation, are the important factors; that

(3) heat radiating ability is economically increased, up to a certain point, by

greater spacing between the grids, and hence (4) for intermittent duty, narrow boss grids with greater ability to absorb heat, are more suitable, but

(5) for continuous duty, wide boss grids, having greater heat radiating capacity, are preferable.

Rheostats for speed regulation are designed either (1) for constant torque duty (current constant throughout the speed range), or (2) for fan duty (current proportional to the speed).

Resistors for intermittent (for example, crane) service are designed to meet (1) general purpose or (2) heavy duty requirements.

The maximum permissible temperatures (Electric Power Club rules) for resistors are 350° C. (thermometer against resistant material), 250° C. (thermometer against embedding material), or 175° C. (thermometer in air issuing from enclosure, one inch distant). Resistors not exceeding these limits in a one hour test (in which time it is considered that the maximum rise will usually be reached) are classified according to the length of time they are in circuit at four-minute intervals, as follows:

light starting duty, 15 seconds on out of four minutes;
heavy starting duty, 30 seconds on out of four minutes;
light intermittent duty, one minute on out of four minutes;
heavy intermittent duty, two minutes on out of four minutes;
speed regulating duty, continuous.

The rating of a resistor as to heat radiating capacity depends upon the degree of intermittency of service. A curve may be plotted showing the relation of its continuous capacity to its intermittent duty capacities.

In designing a resistor the designer determines

(1) the total resistance, from (a) the time on out of four-minute classification (Tables V and VII), and (b) the full load current of the motor;

(2) the number of resistor sections (determined by the number of available points on the controller);

(3) the percentage of total resistance in each step (Table VI); and

(4) the heat radiation capacity per step. The last item is the most difficult to judge. A resistor radiates heat in proportion to the fourth power of its absolute temperature. Its radiation is also affected by the mounting used and the degree to which it is enclosed.

Assuming that the first step is in circuit a less number of seconds than the last step, starting resistors are usually designed with tapered capacity, the last section having greater heat radiating capacity than the first.

Owing to inductive effect the actual peak current during the acceleration of a motor may be assumed as approximately two-thirds of the calculated value.

Speed reduction formula for a resistor in series with the armature (of a direct-current motor; or, in the secondary circuit or of a slip-ring motor):

$$\begin{array}{l}\text{speed reduction obtainable in}\\ \text{per cent of full load speed}\end{array} = \frac{\begin{array}{l}\text{actual load torque required in}\\ \text{per cent of full load}\end{array}}{\begin{array}{l}\text{torque given in column (see Table}\\ \text{V) under particular motor used}\end{array}} \times 100$$

CHAPTER XVIII

PROTECTIVE DEVICES

Overload protection—fuses, circuit breakers—inverse time-element overload relay—desirability of longer time element—low voltage release—low voltage protection—protection against phase reversal—protection against phase failure—protection against failure of shunt field.

INDUSTRIAL controllers are commonly provided with one or more protective devices, such as overload, low voltage release, etc. Some of these devices are designed to protect the motor against abuse; others are for the protection of the operator or the machinery driven by the motor. The more common devices are for protection against:

1. Overload.
2. Low voltage.
3. Phase reversal.
4. Phase failure.
5. Shunt field failure.

OVERLOAD PROTECTION

Fuses.—The oldest form of overload protection is the fuse, consisting of a strip of metal in the main circuit which is melted or fused when the current exceeds a predetermined value. The earlier forms of fuse consisted of an open link. A better and more accurate fuse was obtained by enclosing the fusible link so as to give it a more definite time element and prevent the particles of molten metal from dropping on surrounding objects. Fuses are easy to obtain in the ordinary sizes, as they are carried by most supply houses. Small fuses are inexpensive where only occasional overloads are experienced. Where the motor is worked hard resulting in repeated blowing of the fuse, the cost of fuse renewals, even for small motors, becomes excessive and it is cheaper to use some form of overload device which does not require renewal. A knife switch should be provided for disconnecting the fuses from the line before they are renewed. Even the best designs of fuse are not very accurate, so that it is necessary to overfuse a motor somewhat to be sure of having a fuse of sufficient capacity. The inherent time element in a fuse is a distinct advantage on a motor load, as the fuse will not respond to momentary variations in load, although it will act promptly on excessive overloads.

Circuit Breakers.—The circuit breaker is a switch provided with an overload trip which usually consists of a magnet with a movable core. The attraction of the core of the magnet trips the circuit breaker and opens the circuit. Usually the current at which the circuit breaker trips is adjusted by changing the air-gap between the core and its pole face. Most circuit breakers are reset or closed by hand, although magnetic reset can be provided. No new parts are required for re-establishing the circuit after the circuit breaker has opened. The continual rupturing of the circuit gradually wears away the arcing tips of the circuit breaker so that these must be renewed occasionally. The overload trip can be provided with a dashpot for giving it a time element which should always be done for motor loads.

Overload Relay.—The overload relay is a small circuit breaker which is actuated by a magnet and opens the circuit to the operating coil of a magnetic contactor or to the low voltage coil of a circuit breaker. The relay closely resembles the overload mechanism of a circuit breaker, with the addition of the small contacts referred to above. These relays should be provided with dashpots to give an inverse time element when used with motors. When the overload relay is used in connection with magnetic contactors arrangements can be made for re-establishing the electric circuit from a push button or master switch. When the relay trips its pilot circuit, this circuit may be maintained open by a mechanical latch on the relay or it may be opened through an electrical interlock on the magnet contactor. If a mechanical latch is used on the relay, this latch may be released either by hand or by another small magnet. The two methods are known respectively as "hand reset" and "magnet reset." Where the circuit through the relay contacts is opened on an interlock attached to the main contactor or through another relay, the device is known as "electrically reset." The hand reset on the relay is not recommended for most applications, as it is not desirable for the operator to place his hand near the live parts on the control panel.

Time Element Overload Relays.—Engineers have recognized for years the desirability of having an overload device which would have a time element proportional to the time required to heat up the motor to a definite temperature with various loads. Such a device would give normal overload protection to the motor but would not protect the motor from a short-circuit or severe overload. This, however, could be readily taken care of by a fuse, as it would not be called upon to operate except in cases of emergency. Many motors are operated on intermittent loads, such as cranes, hoists, machine tools, elevators, etc. The motor is capable of carrying a heavy overload for a short period of time. This period of time is much longer than that given by the time element in commercial forms of relays. It is necessary, therefore, to set a relay so as to prevent its operating on these short-time overloads. This results in the motor being without adequate protection in case of too prolonged operation at the maximum load. Large units, such as turbogenerators, have thermocouples incorporated in their windings. These thermocouples are connected to suitable switchboard instruments to indicate the temperature of the windings so that the load can be regulated properly. The same device could be used for opening the circuit breaker, if desirable. These thermocouples, however, are expensive and the apparatus required too elaborate for ordinary motor applications. There is, therefore, a field still open for the development of a long time overload device which will permit the motor to operate at a heavy load for relatively short periods of time and still protect the motor against continuous operation at this load.

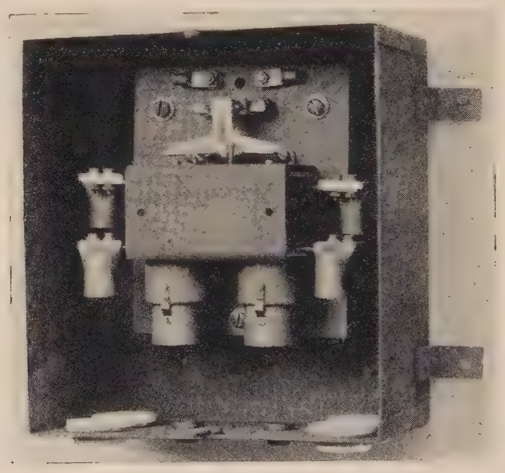

Fig. 186. Dashpot Type of Inverse Time Element Overload Relay

Fig. 186 shows a commercial form of overload relay having a dashpot to give it an inverse time-element feature. Another form of relay, shown in Fig. 187, has a copper disc rotating between the poles of permanent magnets to provide a definite time element. The dashpot type of relay is usually designed to give an inverse time element on increasing loads. Sometimes it is operated from series transformers with saturated cores to limit the pull on abnormal overloads. This latter form of relay is known as a fixed time-element relay. It is the preferable form to use in connection with a controller which is connected to a large power supply line and is provided with a separate feeder circuit breaker for taking care of short-circuits.

Some operators are under the impression that it is desirable to adjust the time element of overload relays. This adjustment would be desirable if a long time element were obtained. Commercial forms of relays do not afford a time element which compares in length to the time required to heat up even small motors. It is desirable, therefore, to obtain as long a time element as possible with the dashpot relay and any adjustment provided should be set to give the maximum time element. But if too long a time element is attempted with the dashpot relay, there is a tendency for it to stick under adverse conditions. It is necessary, therefore, to adjust this time element so that the maximum time given will insure satisfactory operation.

All motor circuits should be protected by feeder circuit breakers or fuses. If the feeder circuit is connected to a very large transformer or to a power circuit having large capacity back of it, the feeder circuit breaker should be of ample capacity to take care of the power ahead of it in case of a short-circuit to the feeder or the apparatus connected to this feeder. This circuit breaker must have a less time element on its trip than that obtained with the overload relay on the controller panel. This latter will require a relay with a fixed time element to insure the opening of the circuit breaker before the contactor on the control panel. The circuit breaker can be set for a high enough value so that it will not be affected by ordinary overloads. The overload device on the control panel should be set low enough to protect the motor against abuse. Where overload relays are used in connection with feeder circuit breakers, it is desirable to have an adjustable time element. In many cases the same overload relay is used for both classes of service. It is therefore provided with an adjustable time element, although the short time element is not desirable when used on the controller.

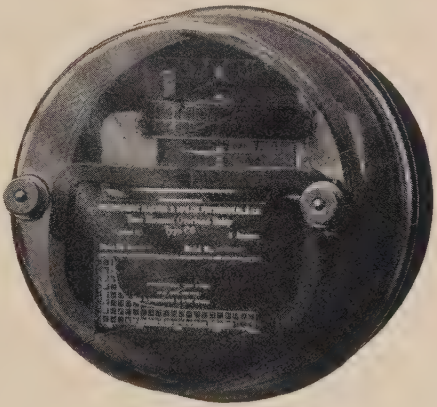

FIG. 187. Induction Type, Time Element Overload Relay

Low Voltage Protection or Release

Devices of this kind are arranged for disconnecting the motor from the line on failure of voltage. The Electric Power Club has recognized two forms of this protection:

(*a*) *Low Voltage Release.*—This provides for disconnecting the motor from the line on failure of voltage, but permits the motor to start automatically when line voltage is re-established. Such a device is the magnetic contactor control with automatic acceleration. It is used for pumps, fans, and similar applications which should restart automatically when the voltage is restored to the line.

(*b*) *Low Voltage Protection.*—This device disconnects the motor from the line on failure of voltage and prevents the motor from being starter again on re-establishment of line voltage. In order to start the motor, the operator must push a button or operate a lever. This latter is a very necessary precaution where the motor is used for driving machine tools or woodworking machinery, printing presses or in fact, any device which might cause injury to a person working on the machine.

These devices are sometimes known as "under voltage" instead of "low voltage," both terms having the same significance. Usually they do not respond to a small drop in voltage.

Phase Reversal Protection

This device operates to disconnect the motor from the line in case one of the phases of the polyphase circuit has been reversed. Such reversals sometimes occur when repair men are installing service transformers or making other repairs. The effect of such a reversal is to cause the motor to operate in the opposite direction. For some applications such a reversal will not cause any damage, but where the motor drives an elevator or hoist a serious accident may result. Some public service corporations supplying electric power to users require the installation of a reverse phase relay device on all elevator motors to protect them from liability resulting from such an accident. There are a number of these devices now in the market. Some of them consist of a small relay having two parts corresponding to the stationary and movable element of a motor or wattmeter. Power supplied to these two parts causes rotation in a definite direction. The torque thus established maintains a contact in the closed position and represents normal operation. If either phase is reversed, the torque of the relay is also reversed which opens the contact and disconnects the control and motor from the line.

Another form of relay is shown in Fig. 188. This relay is made up of standard contactors. The operating coil is supplied through two circuits, as shown. One of these circuits has a resistance in series with it, the other an inductance. The resistance and inductance cause a displacement between the two phases so that when their effect is added the relay is maintained closed. If either phase is reversed, the phase angle is changed, causing the two circuits to oppose each other, reducing the magnetic action on the coil and opening the relay. In the case of the two-phase arrangement shown in Fig. 189, the contactor is provided with two separate coils, one in each phase.

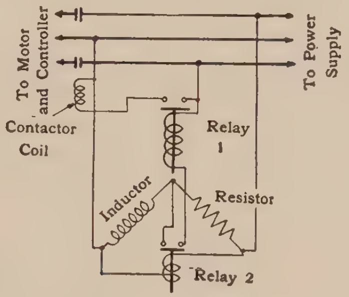

Fig. 188. Combined Phase Failure and Phase Reversal Relay for a Three-phase Circuit

This consists of two small relays, the contacts of which are closed by electromagnets. Relay *2* is connected across one phase of the circuit and remains closed as long as that phase is energized. The coil of relay *1* is connected between the three phases of the circuit, one end of the coil having an inductor in one branch and a resistor in the other branch. This combination brings the current in the two branches of the circuit so that its effect upon the coil of relay *1* is added when the phase relation is correct. On a reversal of phase relation, the current in the two legs of the circuit through the coil or relay *1* oppose each other and the relay drops open. On failure of voltage in any one of the three phases, relay *1* is opened either directly or through the opening of relay *2*. The contactor coil for the control is in circuit with the contacts of relay *1* so that the opening of this relay disconnects the motor from the line

Some devices of this character have been designed to close a circuit on reversal of phase rather than open it. Such devices have special applications in connection with power circuits, but are undesirable for industrial control as the failure of the contacts to make a good electrical connection or the breaking of one of the wires would prevent such a device from operating. Where the contact is closed for normal operation, the breaking of a wire or the failure of the contact would disconnect the controller from the line and automatically stop the motor, which is a safer arrangement.

Phase Failure Protection

Sometimes one line of a polyphase circuit may be opened accidentally. If the motor has not started, it will fail to do so and may be injured by leaving it connected to the line. This can easily happen in a mechanically-operated elevator control where the failure of the motor to start might cause the operator to leave the controller in the running position. By using a low voltage device across two phases of the three-phase circuit, or one relay for each phase of the two-phase circuit, the motor can be protected from such an accident. The relays are connected in such a way that the main switch will not close until both relays are closed. This arrangement is often combined with a phase reversal relay device to give protection to the elevator both from phase reversal and phase failure.

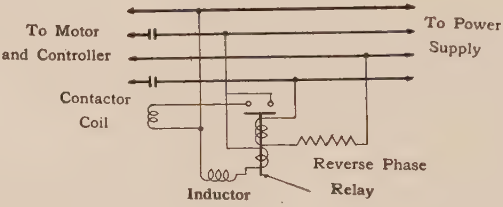

Fig. 189. Combined Phase Failure and Phase Reversal Relay for a Two-phase Circuit

This device consists of a single relay having two coils, the coil across one phase having a resistor in circuit with it. The coil across the other phase has an inductor in circuit with it. The use of the resistor and inductor in the two coil circuits results in the current in each coil being approximately in the same phase relation and their action is added. If, however, the phase relations of the supply circuit are reversed, the magnetic action in the two coils is opposite and the relay opens. On failure of voltage in either circuit, one coil is de-energized and the relay opens. The coil for the magnetic contactor for the main circuit is connected through the contacts on this relay so that when the relay opens the magnet contactor coil is disconnected, opening the contactor and disconnecting the motor from the line

If a motor is rotating and one phase is opened, the motor will continue to operate single phase if the torque does not exceed the single-phase torque of the motor. Such operation, however, causes all of the load to be carried by one phase of the motor and may seriously overheat these windings. If the overload protection is set at a low enough value, it will protect the active phase from an excessive overload. Unfortunately, such overload devices are frequently set too high to afford proper protection. While the motor is operating, voltage is maintained across all three terminals of a three-phase motor or across both phases of a two-phase motor, due to the active phase generating voltage in the inactive circuit. The voltage generated in the inactive circuit is very little less than the normal voltage, so that any phase failure device depending upon a drop in voltage for operating it will not respond, when connected to a rotating motor. Fortunately many installations, such as elevators, hoists, etc., operate for only a short time without coming to rest, so that a phase failure device will operate the first time the motor is brought to rest and prevent restarting it.

SHUNT FIELD FAILURE

Shunt-wound direct-current motors may operate at an abnormal speed and destroy themselves by centrifugal action if the shunt field becomes disconnected from the line. While this kind of an accident is of very rare occurrence, it is thought advisable to guard against it in some particular cases. The usual method of guarding against this form of accident is to provide a relay and place its magnet winding in series with the shunt field circuit of the motor. When this relay is energized, it closes the pilot circuit to the controller. If the shunt field circuit should open, this relay will open the pilot circuit to the controller, which in turn disconnects the motor from the line.

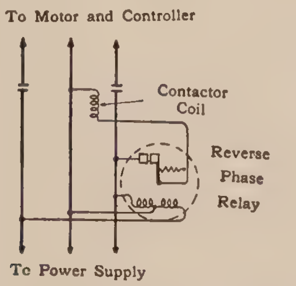

FIG. 190. Combined Phase Failure and Phase Reversal Relay of the Wattmeter or Motor Type

The coil for the contactor in the motor circuit is connected through the contact in the relay. This contact is held open by a spring and is closed due to the torque exerted by two coils connected to two of the three phases. These coils set up a motor action which forces the contacts together against the spring pressure when the phase relation is correct. If either of the three phases is reversed the torque on the watt meter movement is reversed and the contact opens. If the voltage fails in either phase, the torque is reduced to zero and the spring opens the contacts

One serious objection in the use of this relay is the transformer action which takes place in the motor due to sudden changes of load. This action is particularly noticeable when the motor is compound wound. A rapid change in load causes a change in the field flux. This exerts a transformer action on the shunt field windings and may be sufficient to momentarily reverse the current in these windings. This does not mean that the flux in the field circuit of the motor is reduced to zero. It simply means that the rate of change of the flux is sufficient to generate a counter voltage in the shunt field windings large enough to cause a momentary pause in the current through these windings. This is not very hard to do, as the shunt field usually has a very large number of turns, which, multiplied by a small change in flux, will cause a considerable voltage. A reaction of this kind in the shunt field circuit of the motor may cause the relay to drop out and disconnect the motor from the line. The connections to the controller are such that when the relay does open the circuit, the motor will not start again automatically. It requires action on the part of the operator to reset this relay.

A number of devices have been used to delay the action of this relay to prevent an interruption of service. One method consists in adding considerable inertia to the moving parts of the relay by means of a pivoted weight or similar device. Another method is to use a heavy tube of copper around the magnet core. This copper tube acts as the short-circuited secondary of a transformer and delays any change in magnetism in the relay. Usually one or the other of these devices will prove satisfactory, although in aggravated cases, additional precautions must be taken.

Engineers, as a rule, do not consider it necessary to use a shunt field protective relay except with large motors which may run light under certain conditions of load. Safety devices of any character should be avoided where unnecessary, as they add complication to a control equipment and require additional inspection and care to maintain in an operative condition. It is seldom that any safety devices are used other than overload and low voltage. Wherever a safety device is used, it should be tested at frequent intervals to insure its proper operation in case of accident.

SUMMARY OF GHAPTER XVIII

Overload Protection: Protection against overload may be provided by a fuse, circuit breaker, or a relay.

Fuses consist of strips of metal inserted in the electrical circuit, that melt and open the circuit when the current exceeds a predetermined value.

A Circuit Breaker is a switch held closed by a mechanical latch which is opened by a magnet when the current exceeds the value for which the device is adjusted.

An Overload Relay is a relay whose magnet becomes sufficiently energized when the current is excessive to operate a lever opening the control circuit. It may restore the circuit automatically (automatic reset); or may require releasing of a latch by hand (hand reset), or by a magnet controlled either by a push button (magnet reset) or by an interlock on another control device (electrical reset). In the dashpot type of overload relay a dashpot is added to delay the action a few seconds on overloads not excessive but if the overload is large quicker action is permitted (inverse time element). In other types the time required for operation is fixed (definite time element).

Usually short overloads do not injure a motor and adjustable overload devices should be adjusted for the maximum time element. For the motor circuit a device set for a long time element and a low tripping value is preferable, while for an overload device in the feeder circuit the tripping value should be high and operation prompt.

Low Voltage Release, Low Voltage Protection: Low or under-voltage devices, on failure of voltage, disconnect the motor from the line; in the case of low voltage release, the motor resumes operation upon return of voltage to the line; in the case of low voltage protection, the motor does not resume operation upon return of voltage to the line.

Reverse Phase or Phase Reversal Protection: Protection against reversing of a phase, as on an alternating-current elevator circuit, where reversal of the motor's rotation would result disastrously, is provided by a contactor type or by a torque motor or wattmeter element type relay, either of which maintains a contact in the control circuit closed during normal operation and opens it when a phase is reversed.

Phase Failure Protection: A modification of the foregoing providing protection against the failure of voltage in a phase consists in the addition of a low-voltage device which, upon a phase failure, remains closed (due to the generator action of the motor) until the motor is stopped, when it opens and the motor cannot be restarted until the open circuit is repaired.

Field Failure Protection: Protection against the failure of the shunt field of a direct-current motor is provided by a relay which upon accidental opening of the field circuit disconnects the motor from the line.

Use of Protective Devices: Safety devices, because of the increased complications to equipment and the periodical care and attention required, should be included in control schemes only where the harm that may result from their omission is greater than the harm that would result from their failure to operate.

CHAPTER XIX

SERIES-PARALLEL CONTROL AND THE ELECTRO-PNEUMATIC CONTACTOR

Series-parallel control—"series and parallel" control—advantages and limitations of series-parallel control—three methods of transition from series to parallel connections—open circuit transition—shunt transition—bridging transition—advantages and limitations of electro-pneumatic switches versus magnetic contactors.

The series-parallel system of control is applied to two motors, or groups of motors, so arranged that they are connected in series across the line for acceleration to half speed and operation at this speed. The motors may then be connected in parallel and accelerated to full speed. The motors must be mechanically connected together. Otherwise, one motor may accelerate faster than the other, which results in unequal distribution of load. This control is usually applied to cars moving along a relatively horizontal track, such as street railway, interurban and main line cars and locomotives. It is also used for cars in steel mills, coke plants, etc., for the purpose of conveying material from one point to another. These latter cars may be controlled automatically by a push button, or by a standard street car controller. This system of control is sometimes used for slope hoists, where the angle of the slope is small, and for the bridge travel of large ore bridges.

Some controllers are arranged for operation in either series or parallel, the motors being connected permanently in series or in parallel by means of a change-over switch. This switch is interlocked so that the controller must be turned to the off position before the connections are changed. An arrangement of this kind is known as "series and parallel" control. It has only a very limited application. If the resistor is designed for accelerating with one combination of motors, it gives poor acceleration on the other combination, unless the connections to the resistor are changed, which further complicates the control. The only occasion for using such a control would be where there are considerable periods of time when the apparatus is required to operate at half speed, which can be obtained by series connection.

The series-parallel control is usually associated with street railway and steam railway electrifications; the system, however, is applicable to many industrial railways, to mining locomotives, automobile trucks, and similar applications.

The advantages of the series-parallel control are obtained when the period of acceleration extends over a considerable period of time and represents an appreciable part of the complete duty cycle. This is obtained in horizontal traction and many of the applications already enumerated. A saving is accomplished when the motors are connected in series, since the current drawn from the line is one-half of the value which would be taken if the motors were connected in parallel. This is particularly desirable for starting a car or train of cars where the static friction requires a considerable torque in excess of the running torque. Where the period of acceleration is short, the saving is often counterbalanced by the loss during the transition period.

The series-parallel control gives operation at one-half normal speed. This is desirable where trolley cars are operated through a congested portion of the city. If the industrial car is operated automatically, the series combination would give a low speed, from which the stop could be made more gradually than from the parallel combination. The reduction in starting current may sometimes permit the use of smaller feeders for a trolley system or other power distribution. The acceleration of the motors in series to half speed, and then in parallel to full speed, results in a saving in the weight of the resistors, which is considerably more than the additional weight to the control equipment, so that a net saving in the total equipment is obtained.

The disadvantage of the series-parallel control is the added complication in additional parts to the controller. Where rapid acceleration is required, the transition period from series to parallel introduces a time element, which is objectionable. For instance, many industrial motors are accelerated in approximately three seconds. If one second were taken for the transition period, this would add 33 per cent to the total time of acceleration. If the complete cycle were completed in six seconds or ten times a minute, the introduction of this extra second would eliminate one cycle per minute, which might be very undesirable. Even where the bridging system is used and no loss is experienced in the progressive acceleration, the additional time required for the operation of the extra switches would still add a considerable time element to the cycle. Where the motor operates a vertical hoist, or has a similar load, the reduction in torque, which usually occurs at the transition period, would cause a slowing down of the motors which would be very undesirable and would more than compensate for any saving which might be effected during the period of acceleration of the motors in series.

Where the series-parallel system is considered for a new application, careful analysis should be made of the accelerating conditions to determine whether this system of control is the most desirable.

There are three common methods of changing motors from series to parallel. They are known as:

1. Open circuit transition.
2. Shunt transition.
3. Bridging transition.

Open Circuit Transition was the first method introduced. It is illustrated in Fig. 191. Fig. 192 shows the relation between speed and torque during acceleration. In passing from the full series to the first parallel notch, the circuits of both motors are opened.

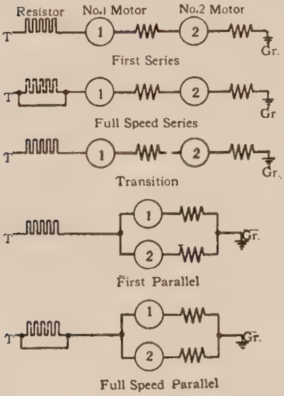

FIG. 191. Steps in the Open Circuit Transition Method of Series-parallel Control

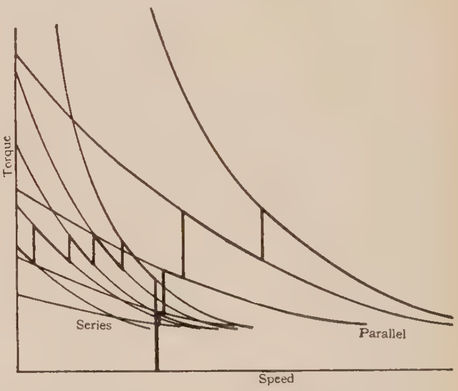

FIG. 192. Speed-torque Curves with Open Circuit Transition

This method is in use for small motors in ordinary service. It is objectionable because the motor circuits are opened, causing arcing at the contacts of the controller and a loss of torque in the motors. The method of control is simple and easily understood. The motors are permanently connected in series and started by inserting resistance in series with them. This resistance is gradually short-circuited, as in rheostatic control. This gives half speed with both motors across the line in series. The motor circuits are then opened and the motors are connected in parallel and accelerated from half speed to full speed by introducing resistance in series with each motor, and gradually short-circuiting it.

Shunt Transition is an improvement over open circuit transition. It is based on the principle that a short-circuit can be placed around the armature and fields of a series motor without injuring the motor. The short-circuiting of the armature through the field reverses the field current, which in turn, reduces the fields and counter e.m.f. to zero. The method of control is shown in Figs. 193 and 194. This system allows one motor to remain active while the other motor is being short-circuited, and in this way, an active torque is maintained on the apparatus during the transition period. In passing from full speed series to the first notch in parallel, the proper amount of series resistance is first inserted and then motor No. 2 is short-circuited. This resistance limits the current to compensate for the absence of the counter e.m.f. of motor No. 2. No. 2 motor is then connected in parallel with No. 1 motor, and the series resistance gradually is short-circuited until the motors are connected across the line, giving full speed. This method of control is employed in the type *K* drum controllers, which are still in extensive use on trolley cars.

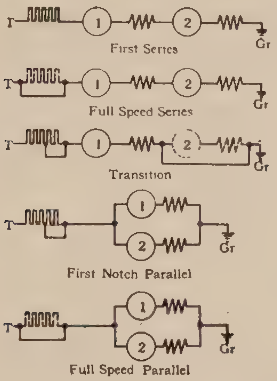

FIG. 193. Steps in the Shunt Transition Method of Series-parallel Control

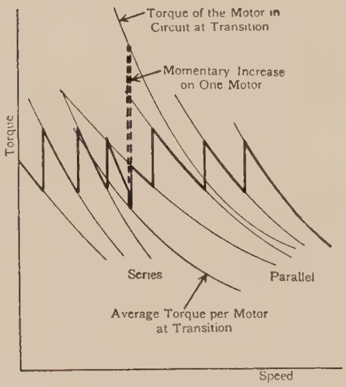

FIG. 194. Speed-torque Curves with Shunt Transition

One of the type *HL* electro-pneumatic controllers uses this principle of control. Fig. 195 shows the connections in detail. An improvement has been made in this controller by using some of the sections of resistors several times. This is permissible, as the use of resistors in series requires the short-circuiting of these resistors in sections. Ordinarily, the first section of the resistor has the maximum resistance and is in circuit the least amount of time. In order to use cast iron grids for these resistors, this first section usually has more capacity, and requires less capacity in proportion, than the balance of resistors, as it is impractical to obtain high ohmic value with a small number of grids. If this section of resistor is now used in another part of the acceleration by connecting it in parallel with other resistors, the weight of metal is used to better advantage, and reduces the total weight of the resistor.

The advantages of this method of transition are:

1. An active torque is maintained upon one motor during the transition period.
2. It is the simplest method in general use.

The disadvantages of this method of transition are:

1. A reduction in torque is obtained during transition, as only one motor is active.
2. This active motor is subject momentarily to a very heavy overload.
3. The change in torque on the short-circuited motor during transition usually results in the motor being momentarily driven by the other motor which takes up the lost motion in the driving gears in the reverse direction. When the motor becomes active again, this lost motion is again taken up in the positive direction. This double action results in two shocks in the driving machinery and has a tendency to cause excessive wear and loosening of parts.

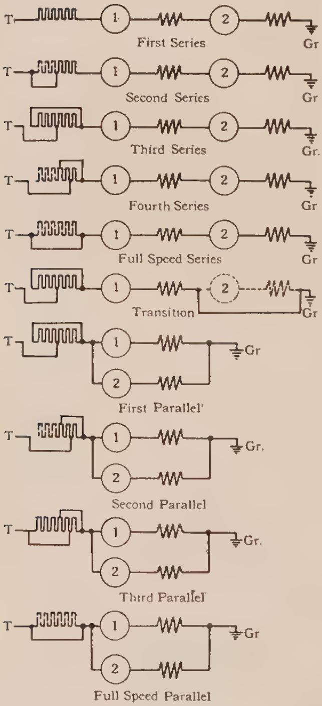

FIG. 195. Steps in Shunt Transition Using an Electro-pneumatic Controller

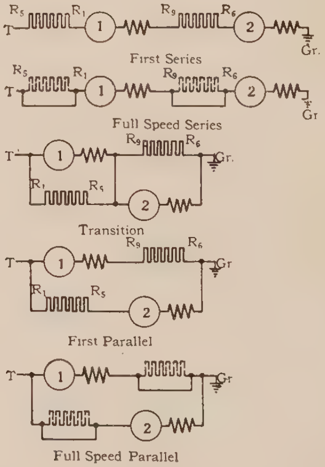

FIG. 196. Steps in the Bridging Transition Method of Series-parallel Control

Bridging Transition.—The transition from series to parallel by this system consists in placing a shunt or bridge between the motors so that all the motors are active during the transition period. This is illustrated in Figs. 196 and 197. Its operation is similar to that of a Wheatstone bridge. The two sides of the bridge consist of the motor plus a resistor. If the drop in voltage through the resistor is equal to the drop through the motor, the two parts of the circuit connected by the bridge will be at the same potential, and no current will flow. It is difficult to obtain this exact balance with manual operation; it can be closely approximated, however, where automatic acceleration is used. The arrangement of circuits for this method consists in a portion of the series resistance being inserted between the two motors. Passing from the full speed series position to the first parallel notch, the two sections of resistance are inserted in parallel with the motors, so that each motor has a circuit from trolley to ground through the motor and a section of resistance, the final series connection forming the bridge of the circuit. This bridge circuit is then opened and the resistance gradually short-circuited until the motor is brought up to full speed. In practice extra resistance is inserted ahead of the first motor, to obtain adequate starting resistance, and to protect the first motor on resetting the circuit breaker.

If the resistors are so adjusted that more current passes through the two resistors than through the two motors during the bridging period, the opening of the bridging switch will interrupt this excess current and give an increased torque on the motors, equivalent to an additional notch of the controller. This notch can be so adjusted as to be equal to the other accelerating notches, so that the acceleration through the transition period compares favorably with that during other periods.

The advantages of this method of control are:

1. An active torque is maintained on the two motors during the transition period.
2. By properly adjusting the resistors at the time of transition, an active accelerating notch is obtained at this time, which gives a smooth acceleration. Since both motors are active, no jerks are obtained. These advantages make this method of transition the best for heavy traction applications.

The disadvantages of this method of control are:

1. Added complication.
2. Additional switches.
3. Increased arcing. This latter is objectionable only where drum controllers are used. Contactor switches are well adapted for this service and the arc can be properly distributed so as not to cause excessive wear.

The use of series-parallel control in railway work has identified it with the electro-pneumatic controllers. This controller is in general use for railway work but is also used for some industrial applications where compressed air is available, or where the installation is of sufficient size to warrant the use of compressed air. Often compressed air proves a valuable means for operating mechanical brakes, clutches, and similar apparatus, so that on some large ore bridges and similar industrial applications, the electro-pneumatic controller has been used instead of the magnetic contactor controller.

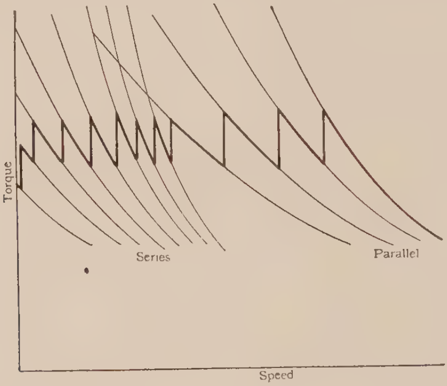

FIG. 197. Speed-torque Curves with Bridging Transition

ELECTRO-PNEUMATIC SWITCHES

When the railway industry developed from small individual cars to multi-unit operation it became necessary to design control apparatus which could be operated from a master switch placed on the platform of the leading car. Several methods of operating the control were tried. The two principal methods used at that time, both of which are now in successful operation, were the magnet-operated contactors and the electro-pneumatic switch. Other methods, such as the pilot motor-operated and air-cylinder-operated controllers, have been used, and still have a limited application, but the railway industry today has been built up on the foundation of individual contactors or switches operated either by a magnet directly or by air pressure controlled by an electro-magnet.

The electro-pneumatic switch was designed primarily for railway work but it has been used successfully for a number of industrial applications, such as ore bridges, electric shovels, mine hoists, etc. Wherever compressed air is available this switch can be applied and in some cases its characteristics make it a more desirable switch than the one operated directly by a magnet.

The switch is illustrated in Figs. 198 and 199, the latter being a cross-section drawing of the switch. The contacts are of the rolling type, the same design as those of the magnetic contactor. They are opened by a spring in the air cylinder and closed by air pressure underneath the piston. Air is admitted to the cylinder by a small valve operated by a magnet. The work done by this magnet is so small that a very low wattage in the coil is sufficient for the purpose. This makes it possible to design a small magnet which will operate over a wide range of voltage and one that can be used on a low potential circuit. The design of the switch is such that a failure of air pressure results in opening the switch. The magnetic blowout is smaller in design than those used for magnetic contactors, with possibly one exception. The opening in the arc box confines the arc to a movement in the horizontal direction. This is necessary in order to permit the mounting of the switch underneath a car or in rows in a locomotive cab. As explained in a previous chapter the arc is ruptured by stretching it and cooling it. On account of the arc being moved only in the horizontal direction the arc box on the railway contactor is usually larger than for the corresponding industrial contactor which permits the arc to be moved both horizontally and vertically. In other words, the industrial contactor has a box which is opened at the top as well as the side.

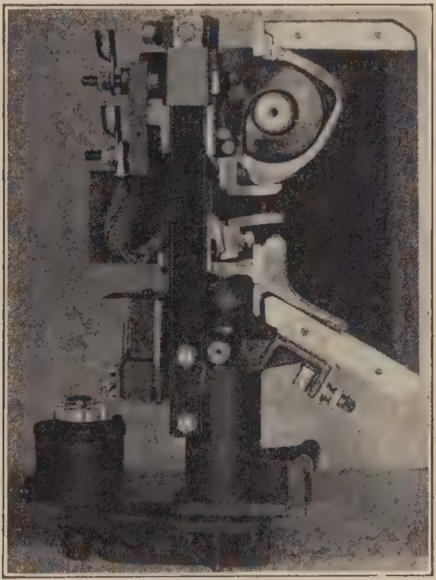

FIG. 198. Electro-pneumatic Switch

The width of the switches for railway service is kept down to a minimum in order to reduce the overall length of the controller which is made up by mounting switches side by side. Weight is also an important factor which influences the construction of the switch. This is evident

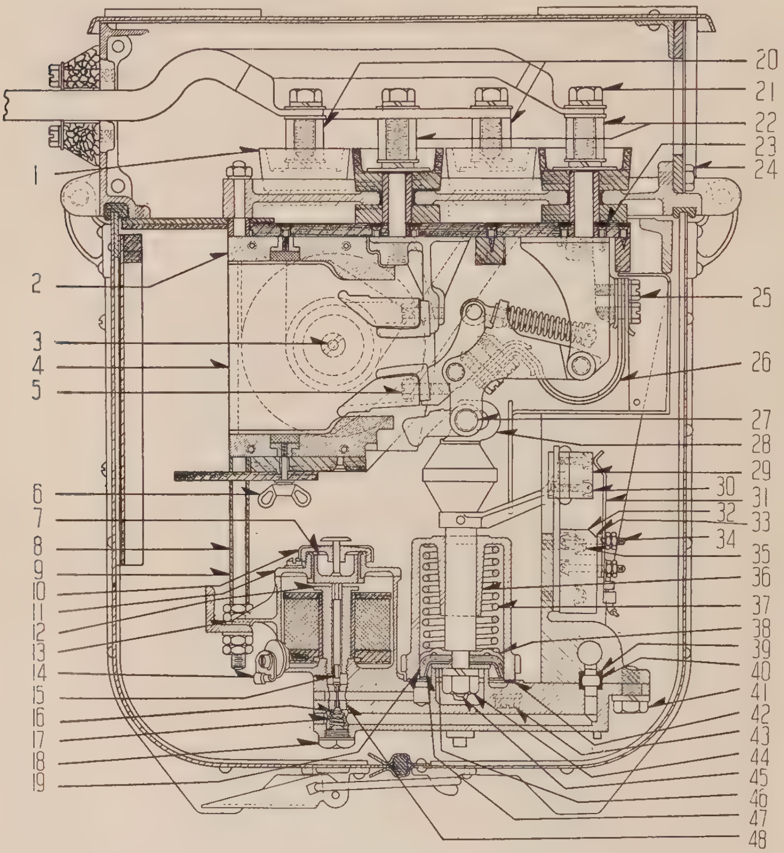

FIG. 199. Cross-section of Electro-pneumatic Switch

DETAIL LIST OF SWITCH PARTS SHOWN IN FIGURE

1. Insulating washers.
2. Arc chute.
3. Screw holding pole piece on blowout coil.
4. Arc chute side.
5. Bolts holding switch contacts.
6. Wing nut holding arc chute in place.
7. Armature of magnet valve.
8. Bolt holding angle iron which supports front end of valve magnet casting.
9. Insulating tube.
10. Magnet valve cap.
11. Iron cover of valve magnet.
12. Magnet valve core.
13. Foot supporting front end of magnet bracket.
14. Magnet coil terminal.

from the minimum amount of iron which is used in the framework. The latest designs of these switches are of the self-contained unit type, the switch parts being clamped to insulated steel bars which form the framework of the switch and give the maximum strength with a minimum weight. This unit construction permits the air-operated switch to be assembled in a variety of ways the more readily to adapt it to different classes of service. The former method of building these switches in groups of 8 to 10 in a cast iron frame resulted in a heavier controller and one that lacked flexibility.

The arrangement of air-operated switches shown in Fig. 200 is typical for an ordinary surface car. The switches are mounted in a sheet metal enclosure which protects them from dirt and water. The sides of the box are hinged to make the operating parts of the switch accessible for inspection and renewals.

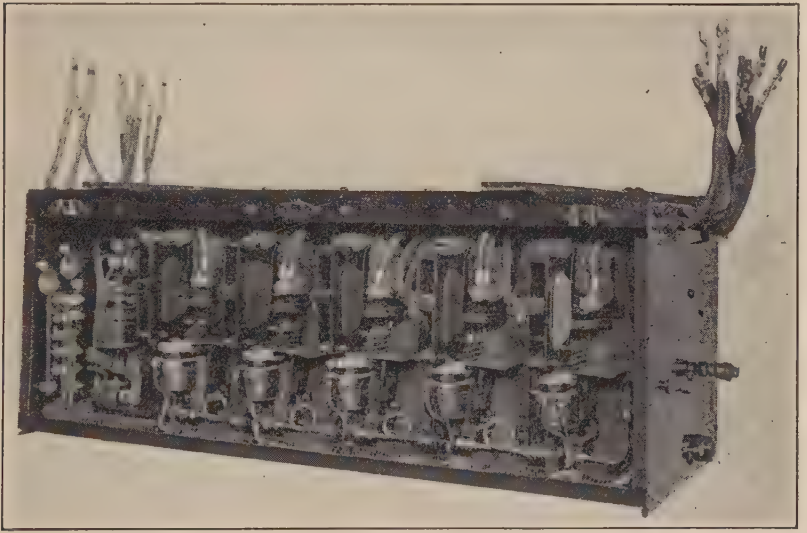

FIG. 200. Arrangement of Air-operated Switches in Ordinary Surface Car

The controller is divided into two groups, one of which carries the reverse switch and the other the sequence switch. The sequence switch is a small drum controller actuated by air cylinders and controlled by magnet valves. The contact fingers energize the air switches in the proper sequence for accelerating the motors. The speed at which the sequence switch drum rotates is adjusted to give the desired rate of acceleration. When the master switch is moved to the off position the sequence switch returns to its initial starting position. This insures that the motors are started in the proper manner each time the master switch is moved from the off position to one of the running notches. The sequence switch will stop at intermediate notches corresponding to positions on the master switch. The reverse switch is interlocked with the line switches so that it is operated only when the controller is disconnected from the line.

The valve magnets are operated on a low potential circuit which is either supplied by a storage battery or from a resistance which is connected across the line, the valve magnets being in shunt with the portion of this resistance at the grounded end. The voltage used on the valve magnets is normally 20 volts. On account of the low voltage at which the valve magnets operate there is very little arcing on the interlock fingers which permits their being arranged in a very compact manner.

The use of air as an auxiliary for operating the controller has been applied to a number of different types of control. Air pressure is available at the present time on practically all excepting very small surface cars. The amount of air used in operating a controller is small in comparison to the amount taken by the air brake, so there is little objection to using air as an auxiliary for operating the controller. The only extra precaution required is to see that the piping is installed so as to drain the moisture from the air system. Air cools very rapidly when it is expanded and has a tendency to cause frost or ice particles to form in the ports to the valve and cylinder, particularly when the outside temperature is very low. This difficulty is sometimes experienced when the piping is installed by persons not familiar with this system of control. If properly installed the air is cooled after being compressed, which precipitates the moisture in the form of water that can be readily drained off. The only other source of trouble is dirt, which can be easily removed by a fine mesh strainer.

An important detail of these switches is the piston leather. There is perhaps no detail of the entire switch which has received more thought and on which more research work has been done than on the piston leather and method of mounting this leather in the cylinder. Leather is porous and if used in its natural condition it will have excessive air leakage through these pores. It is therefore necessary to treat this leather partly for the purpose of filling up the pores and partly for the purpose of giving it the proper mechanical structure. The practice at this time is to use a piston leather made up of three layers or thicknesses of leather. This gives the desired flexibility as well as reduces the leakage to a minimum. The piston leather has a phosphor bronze expander mounted inside of the cup. This causes the leather to exert an initial pressure against the inside of the cylinder. When air is applied this pressure is increased and makes a tight joint between the leather and the walls of the cylinder. The compound with which the leather is impregnated must withstand a considerable variation in temperature. In cold weather the cars may be idle for a long time and the temperature within the cylinder may go to zero or even lower. When the car is in service the current which passes through the controller heats up all of the parts in the switch group and if the outside temperature is warm, as especially in the southern states, the temperature inside the cylinder becomes very high in comparison. The ordinary compound with which feathers are impregnated has a tendency to be very stiff at low temperatures and very soft at high temperatures. It is therefore necessary to use a process for impregnating that will give satisfactory operation over a wide range of temperature.

The electro-pneumatic control has a number of fundamental advantages which may be briefly summarized as follows:

1. High pressures can be used between the contacts carrying the main current.
2. A strong spring can be used in opening the contacts.
3. The valves require very little force to operate them and the magnets require only a small wattage for their successful operation.
4. On account of the above successful operation can be obtained with a wide range of voltage on the control circuits.
5. The power available for operating the switch permits a rugged construction of the interlock contacts.
6. The low voltage at which the valve magnets operate permits of a very compact arrangement of interlock details.
7. The design of the switch is such that its operation is independent of its position and is also independent of vibration.
8. The speeds at which the switch opens and closes can be independently adjusted by changing the size of the air inlet and exhaust.
9. The switch closes at a positive uniform speed and eliminates the hammer blow present in magnet operated contactors. This reduces the bouncing of the contacts during closing to a minimum and in many cases entirely eliminates it.
10. The pressure on the contacts carrying the main current is independent of the line voltage. With control of this type, being independent of voltage, the car can be operated at any voltage which will cause the motors to turn over. On the other hand the movements of the switch will be uniform and satisfactory at voltages greatly in excess of normal.
11. On account of the small size of the valve magnet it has very little induction and therefore responds quickly both in opening and closing the valve; the small inductive effect does not interfere with the coils connected in multiple.

The limitations of this form of control may be summarized as follows:

1. It requires a reliable source of air pressure for operation. The normal air pressure is usually 70 pounds. This air pressure should not drop below 50 pounds and should not exceed 100 pounds. In practice a

governor maintains the air at normal pressure so that the switches may operate under the most favorable conditions.

2. The air must be clean and dry.
3. The use of air as an auxiliary requires piping connections to be made to the controller in addition to the wiring connections. This is offset to a considerable extent by the use of low voltage control circuits, which simplifies the wiring details.
4. Piston leathers need renewing from time to time. This, too, is offset somewhat by the absence of trouble with the valve magnets and interlocks on account of the small power used in this circuit.

SUMMARY OF CHAPTER XIX

Series-parallel, "Series and Parallel" Control: In series-parallel control two motors or groups of motors mechanically coupled are connected in series and accelerated to half speed, then connected in parallel and accelerated to full speed. In "series and parallel" control the transfer of connections is made by means of a change-over switch so that the motors may continue operation either in series or in parallel.

An advantage of the series-parallel system of control is that, with a saving of current, it gives a half normal speed, useful in starting cars or in slowing down before stopping. A limitation is that it complicates the apparatus and increases the time required for acceleration.

There are three methods of transferring from the series to the parallel connections:

Open Circuit Transition: (1) the motors and resistor are connected to the line in series;

(2) the resistor is gradually short-circuited, accelerating the motors to half speed;

(3) the circuits are then opened and the motors are reconnected to the line in parallel, with the resistor again in circuit;

(4) the resistor is short-circuited, accelerating the motors to full speed.

An objectionable feature is that the motor circuits are opened, causing arcing and loss of motor torque.

Shunt Transition: (1) the motors and resistor are connected to the line in series;

(2) the resistor is gradually short-circuited, accelerating the motors to half speed;

(3) the field and armature of motor number 2 are short-circuited (the armature short-circuited through the field reverses the field current, reducing the field and counter e.m.f. to zero); at the same time part of the resistance is reinserted in the circuit (to compensate for the absence of the counter e.m.f. of motor number 2);

(4) motor number 2 is connected in parallel with motor number 1;

(5) the reinserted resistance is short-circuited, bringing the motors up to full speed.

This method is simple and has the advantage of maintaining an active torque on one motor during the transition period but by shorting out one motor reduces the total torque, overloads the active motor, and gives two distinct shocks to the driving machinery.

Bridging Transition: (1) the motors and resistors are connected to the line in series;

(2) the resistors are gradually short-circuited, accelerating the motors to half speed;

(3) the resistors being short-circuited, may now be disconnected from the line, and are reconnected across each of the motors, but overlapping a section of the line between the two motors, which now forms a bridge between two parallel circuits from trolley to ground, each consisting of a motor and resistor;

(4) the bridge is removed, leaving the motors in parallel with a resistor in series with each. Any unbalanced current carried by the resistors is now diverted to the motors, increasing their torque;

(5) the resistors are short-circuited, accelerating the motors to full speed.

During transition the torque is kept active and smoother acceleration is obtained by the extra accelerating notch made available (by step 4), but more apparatus with resulting complications is required and the increased arcing is objectionable when drum controllers are used.

Electro-pneumatic Switches: In the electro-pneumatic switch contacts of the rolling type are closed by a piston working in a cylinder to which compressed air is admitted by an electro-magnetically controlled valve. On deenergizing the magnet the valve is closed, the cylinder exhausted, and the contacts are opened by a spring. The contactor also opens if the compressed air supply fails. The switch is made narrower in width and lighter than magnetic contactors. The complete controller is divided into two groups of switches, one forming the sequence switch and the other the reverse switch.

Drainage must be provided for water accumulating in the piping system. The piston usually consists of three layers of impregnated leather with a phosphor bronze expander. The impregnating compound should not become too stiff in cold weather nor too soft in warm weather.

In comparison with the magnetic contactor, the advantages of the electro-pneumatic switch lie in the high contact pressure available, the small amount of power and the low voltage required to operate the valves, the lighter and more compact design possible, but a dependable supply of clean, dry air is essential, a piping system is necessary in addition to the electric wiring, and the piston leathers require renewal.

CHAPTER XX

VOLTAGE CONTROL OF DIRECT-CURRENT MOTORS

Control of direct-current motors by varying the supply voltage—multivoltage system—variable voltage system—flywheel reduces demand peaks—steadying power demand with slip regulator—how the size of flywheel is determined—reversing mill sets—field forcing—keeping the voltage constant—overload operates only during deceleration—keeping the armature current constant—preventing reversal of field's polarity—when is residual magnetism desirable?

If a direct-current motor has its field excited at a constant voltage, its speed will be proportional to the voltage impressed on its armature. The methods of obtaining a reduced voltage by means of resistance in series with the armature have already been described. Another method that is little used at present is to provide a source of power, using four or more power wires, the voltage between the different wires being proportioned so that a considerable number of operating voltages can be obtained by connecting the motor armature to different pairs of wires. This method is known as the "multivoltage system." It is objectionable because it requires a number of power wires and also special generator equipment. There are also power circuits provided with two outside wires and a central or neutral wire, the voltage between the outside wire being double that between either wire and the neutral. These systems usually have voltages of 115 and 230 respectively, and are used for a limited number of industrial applications.

The increasing size of direct-current motors for hoisting, and the application of motor drive to reversing steel mills during the last ten years has brought into general use a system of voltage control, in which a separate generator is provided for each motor. This generator may be driven from any source of power but is usually driven by a constant speed, alternating-current motor. The armature of the generator is connected directly to the direct-current motor, as shown in Fig. 201, both machines having their fields supplied from a constant voltage exciter. The slow speeds of the motor are obtained by reducing the strength of the generator field. If the generator field is reduced to zero and energized in the reverse direction, the rotation of the motor will be reversed. The controller in Fig. 201 shows one means of doing this. The rheostat consists of a closed circuit in the form of a circle. Points *A* and *B* are connected to the + and — side of the exciter, and *C* and *D* are connected to the generator field. When the rheostat is in the position shown, the generator field is zero, and consequently the motor speed is zero. If contact *1* is moved to coincide with point *A*, contact *2* with *C*, contact *3* with *B*, and contact *4* with *D*, current will flow from the exciter to *A* through *1* and *2* to *C*, thence through the generator field to *D* and from contact *4* to *3* to *B*, and thence to the exciter. This will give the maximum field strength to the generator and cause the motor to operate in a forward direction at full speed. Any position between the one shown in the diagram and the one just described, will give intermediate values of field strength and cause the motor to operate at reduced speeds. If the controller is moved so that contact *1* coincides with point *C*, contact *4* with point *A*, etc., current will flow from the exciter to *A* through contacts *4* and *3* to *D*, through the generator field to *C*, through contacts *1* and *2* to *B* and then to the exciter. This will cause the motor to operate at full speed in the reverse direction. Intermediate positions of the control will give intermediate speeds.

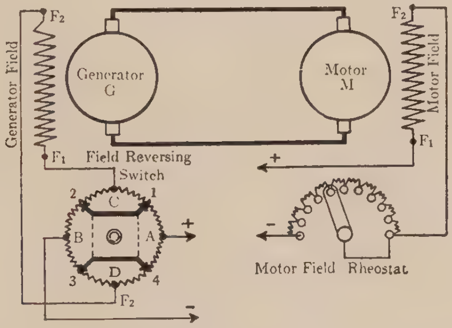

FIG. 201. Connections for Reversing a Steel Mill Motor

Showing the field reversing switch of the alternating-current generator

The advantage of such a method of control is obvious. The speed and direction of rotation of the large motor *M* in Fig. 201 is controlled by switching the small field current of generator *G*. This current may be in the neighborhood of 100 amperes, while the armature current flowing from *G* to *M* may be several thousand amperes. This method gives a large number of fixed running speeds and the only losses which occur are the usual losses in the generator and motor in addition to the rheostatic losses in the field control.

The speed of motor *M* may be retarded by reducing the generator voltage to a lower value than the center e.m.f. of the motor. This causes the motor to regenerate and produces dynamic braking. If the generator *G* is driven by a suitable motor, this method of slowing down will return power to the line. If it is driven by an engine, the generator cannot absorb the power, and the regenerated current must be wasted in a resistance.

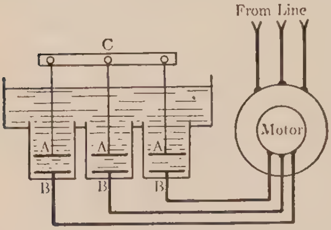

FIG. 202. Connections of Slip Regulator to Induction Motor

The field of motor *M* can also be varied to increase the speed range of the combination. It is found in practice that the motor *M* can be arranged for speed control of 1:1.5 or 1:2 by varying its shunt field without much additional expense. If less than the full range of operating speed is obtained from the generator, a smaller generator can be used. Therefore, the combined field control of the generator and field control of the motor gives cheaper commercial apparatus than to obtain the entire range of speed control from the generator. This double method of control may seem complicated, but as it is usually combined in one master switch, very little additional apparatus is required.

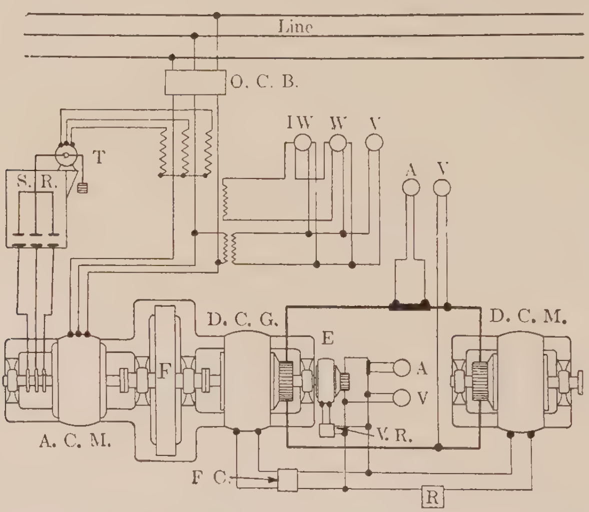

FIG. 203. Diagram of Connections of Equalizer Flywheel Hoisting Set

A.C.M., wound-secondary induction motor; *F*, flywheel; *D.C.G.*, separately-excited direct-current generator; *E*, exciter; *D.C.M.*, separately-excited direct-current motor; *S.R.*, automatic liquid slip regulator; *T*, torque motor for slip regulator; *O.C.B.*, oil circuit-breaker; *F.C.*, reversing field controller for generator; *R*, rheostat for motor field; *V.R.*, voltage-regulator for exciter. *A*, ammeter; *V*, voltmeter; *W*, watthour meter; *I.W.*, integrating wattmeter

When the generator G is driven by a motor, this method of controlling the operating motor is usually combined with a system for reducing the maximum power demand from the generating station. The power supplied for large installations is usually alternating current, so the generator G in Fig. 201 is driven by an induction motor, shown in Fig. 202. On the motor-generator shaft is placed a large flywheel, which is used for storing energy during the low demand period of the cycle and for supplying energy during the maximum demand periods. This flywheel performs a similar function to a storage battery floating on the direct-current system. The flywheel gives out energy or absorbs energy, depending upon the speed of the motor-generator set.

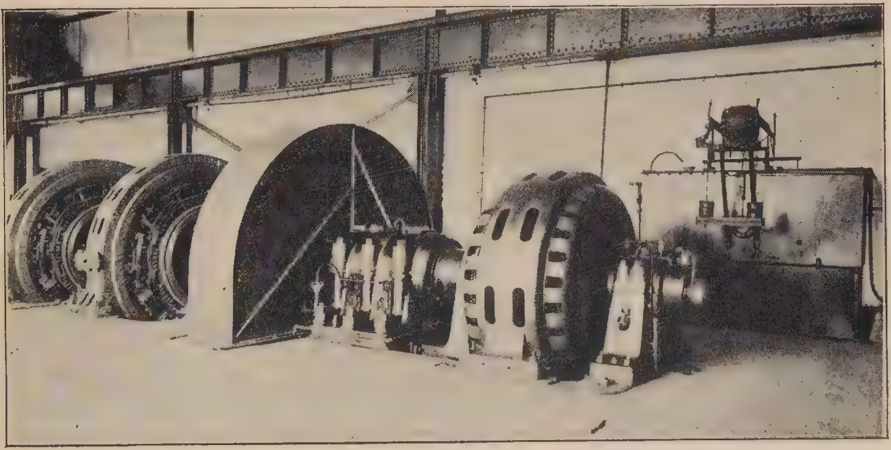

Fig. 204. Equalizer Flywheel Hoisting Set, Showing Automatic Liquid Slip Regulator

The driving motor for this set is provided with a wound secondary and a slip regulator is introduced in its secondary circuit. If the resistance in this secondary circuit is varied automatically with the load, the motor will take an approximately constant amount of power from the line. This is only desirable above, say, full load on the motor. If the demand for power is in excess of this load, the slip regulator introduces more resistance in the motor secondary and allows the motor-generator set to slow down, so that the flywheel can supply this excess of power. When the demand on the generator is less than normal, the resistance in the secondary of the induction motor is decreased and the excess power input is used in accelerating the flywheel, thus storing up mechanical energy to be given out later when an excess demand occurs.

A diagram combining the control of the motor-generator set with the control of the operating motor is shown in Fig. 203. This diagram is merely a scheme of connections intended to illustrate the principle, and does not show any of the control apparatus in detail. The slip regulator in the secondary of the induction motor consists of three fixed electrodes marked *B* in Fig. 202. Each of these electrodes is insulated and connected to one of the slip rings of the induction motor. Above them in the liquid are suspended three electrodes marked *A* attached to a common support *C* and electrically connected through this support. The liquid in the tank, known as the "electrolyte," is a solution of washing soda and water. Referring to Fig. 203, it will be seen that the movable electrodes are raised or lowered by a small torque motor *T* which is energized from three series transformers in the primary circuit of the induction motor. The weight of the moving element is partly counterbalanced, but is still sufficient to move the plates together. The torque motor tends to separate the plates. This motor operates in the same manner as an ammeter; the plates move up or down until the torque of the motor just balances the weight of the moving element, which occurs at substantially the same current values for all positions of the plates. The friction in a commercial regulator does not require more than five per cent difference between the torque for raising or lowering the plates.

The upper curve in Fig. 205 shows the regulation obtained with one of these slip regulators in commercial work, as compared with the regulation obtained with a magnetic contactor control for cutting resistance in and out of the secondary of the motor, as shown in the lower curve. These curves show the advantages of the liquid regulator, and that the maximum power input is quite uniform. The minimum power input depends largely upon the way in which the load comes on and off the operating motor, so that these low peaks decrease to a very small value if the demand for power is small over a considerable period of time.

An exciter is shown mounted on the shaft of the motor-generator set in Fig. 203. As the speed of this exciter varies with the speed of the motor-generator set, it is necessary to provide a voltage regulator, in order that the voltage of this exciter will remain constant over the speed range which is obtained in practice. This is a much simpler arrangement than to use a separately-driven exciter.

It is becoming the practice of power companies to make a charge based upon the maximum demand required from the power system. This is a just method of charging for power, as the size of the generating station must be determined by the maximum demand of the customers. Where a large motor is applied to a hoist, considerable power is taken from the line to accelerate the hoist, if the motor is connected directly to the supply system. The charge for power may be large, on account of this maximum demand. If the motor is operated from a flywheel motor-generator set, as previously described, the maximum demand can be kept quite low, as shown in Fig. 205, particularly if a liquid regulator is used, so that a reduction is made in the power bills by using this system. Another saving results from the regeneration of power when the load is reversed. When operating a mine hoist with this voltage system of controlling, there is very little rheostatic loss, so that less power is taken and a large percentage of the energy given out by the descending hoist is returned to the line by regeneration.

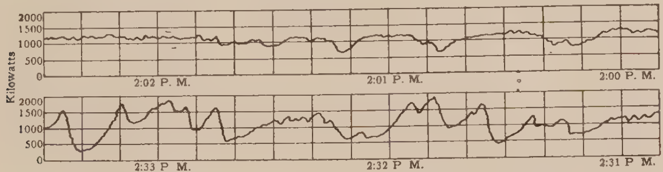

FIG. 205. Power-demand Curves of a Typical Hoisting Set

Upper curve shows the regulation using a slip regulator; lower curve the regulation using magnetic contactor control

It is not difficult to determine the size of a flywheel to absorb the peak loads when used in connection with a motor-generator set. A curve should be drawn showing the relation between the horsepower required at any particular instant and the time. It is usual to plot the horsepower as ordinates and the time as abscissae. From this curve, the average input can be obtained and the maximum demand over any given period of time.

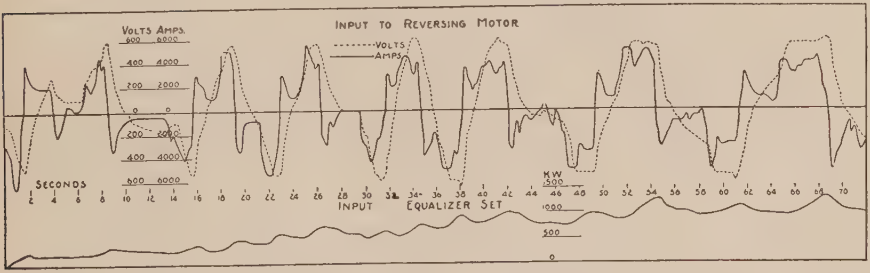

FIG. 206. Curve Showing Input to Reversing Motor

To illustrate, in Fig. 207 is given a load-time curve of a hoisting set, to lift 5000 lbs. at 1200 ft. per min. The accelerating and retarding periods will be equal to 1760 horsepower seconds and the constant speed periods will be 3540 horsepower seconds, making a total of 5300 horsepower seconds in excess of the average requirements. This represents the total energy which must be given out by the flywheel over the maximum demand period. This energy must be returned to the flywheel during the periods where the power demand is less than the average.

The weight of the flywheel depends upon the type of construction and the maximum peripheral speed. Let V_1 equal the velocity in feet per second at the radius of gyration for maximum speed, and V_2 for the minimum speed. The simplest form of flywheel and one of the best is made up of solid circular plates. For this type of wheel, the radius of gyration is equal to 0.707 of the wheel radius. If 20,000 ft. per min. is selected as the maximum peripheral speed, which corresponds to good practice, the maximum velocity at the radius of gyration will be:

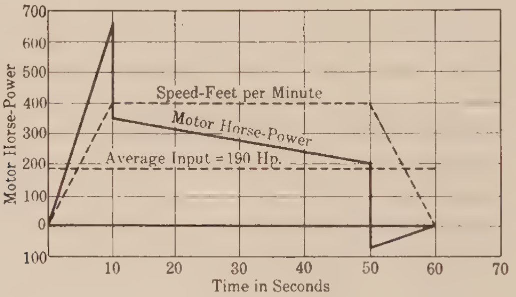

FIG. 207. Load-time Curve of a Typical Hoisting Set

$$V_1=\frac{20{,}000\times0.707}{60}=236 \text{ ft. per sec.}$$

If a minimum speed is assumed equal to 85 per cent. of the maximum speed, which is good practice, the minimum peripheral speed will be

$$V_2=236\times0.85=200 \text{ ft. per sec.}$$

The weight of the flywheel can now be calculated as follows:

$$W=\frac{\text{Hp. sec. to be supplied}\times550\times2g}{V_1^2-V_2^2}=\frac{5300\times35{,}400}{(236)^2-(200)^2}=12{,}050.$$

The rotating element of the motor and the generator furnish some flywheel effect, so that the horsepower seconds of the flywheel effect obtained from these two units can be subtracted from the total in calculating the size of the flywheel if it is desirable to figure very closely.[1]

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[1] With a slip regulator it is possible to keep the motor load almost constant at the average value. Without a slip regulator the motor load increases with the decreasing speed, and the calculation is more complicated. See article on "Relation of Flywheel and Motor Capacity for Industrial Loads," by S. A. Fletcher and Chas. R. Riker, *Electric Journal,* March, 1912, p. 270.

The scheme of control illustrated in Fig. 203 is applicable to mine hoists and smaller reversing sets for driving the main rolls in steel mills. Many steel mill applications require much large equipments. If the diameters of the rotating parts are increased the stored energy will increase as the square of the diameter which materially increases the work required for reversing the equipment. It is, therefore, better engineering practice to divide the motor and generator into two units. Fig. 209 shows a diagram of the double unit set. The main circuits between the generators and the motors might be arranged so that each generator operated its own motor or the generators and motors might be coupled in series. The series arrangement is preferable as it insures an even distribution of load between all four machines. The objection to this arrangement is the large armature current if the voltage per machine is 250 or a total of 500 volts to ground; but if the voltage per machine is 500 volts additional insulation is required. The arrangement shown in Fig. 209 avoids both these difficulties by connecting the motors and generators alternately in series, the current passing from generator No. 1 to motor No. 1, thence to generator No. 2 and motor No. 2 back to generator No. 1. This arrangement can be readily extended to additional machines if a larger output is required.

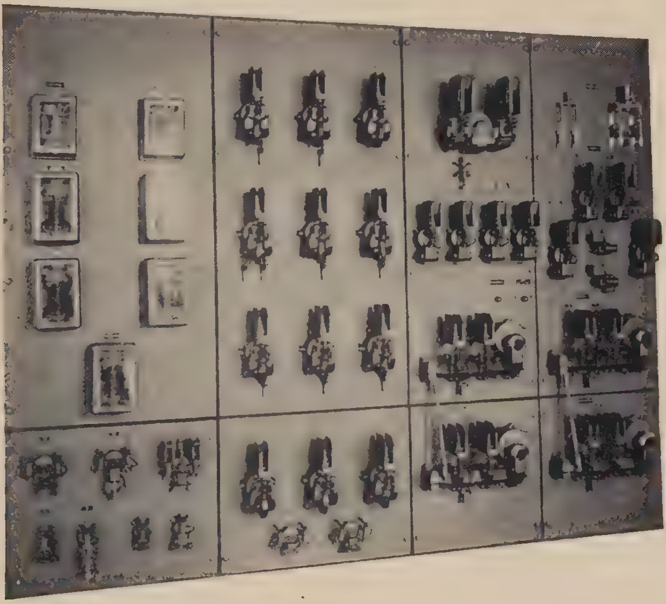


FIG. 208. Electromagnetic Control Panel for Reversing Mill Set

In rolling steel it is very desirable that the motors have compound characteristics but the armature currents are too large to reverse the series field each time the shunt field is reversed, so that another arrangement must be used. This consists of a small generator, *K*, Fig. 209, forming part of the exciter set. The fields of this generator are in series with the armature current of the main motors. The voltage of the machine *K* is, therefore proportional to the load on the main motors and this machine can be used to excite windings on the motors. These windings carry only a small current and can be reversed when the fields of the shunt generators are reversed.

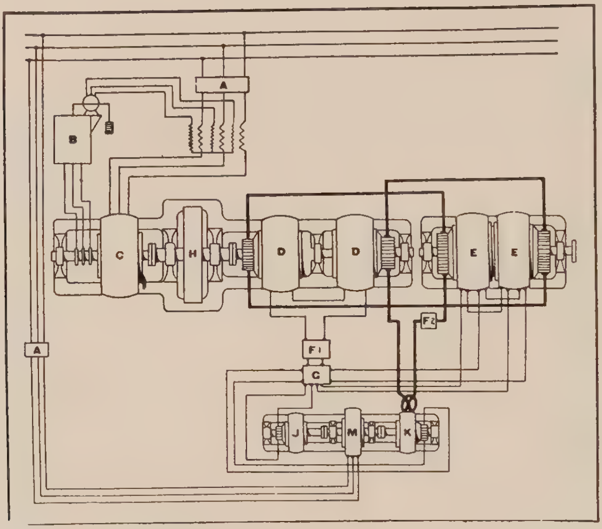
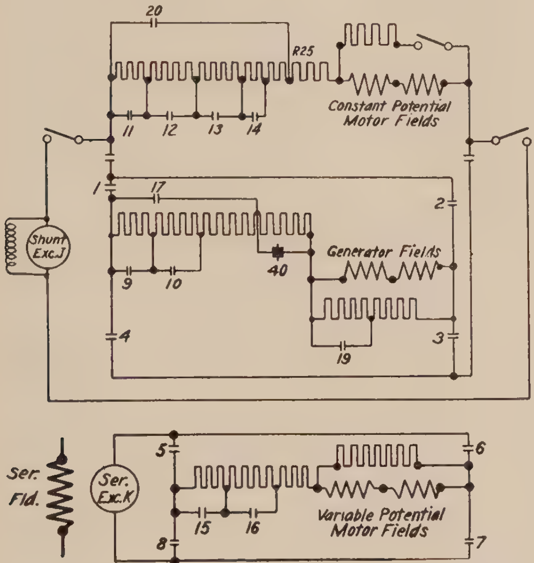


FIG. 209. Schematic Diagram of Connections for Double-unit, Reversing-mill Motor

A, Oil circuit breaker with no-voltage and overload trip; *B,* Automatic liquid slip regulator; *C,* Alternating-current, wound-rotor induction motor; *D,* Direct-current, separately-excited generators; *E,* Direct-current, separately-excited motors; F_1, Circuit breaker in generator fields; F_2, Circuit breaker in main circuit; *G,* Field controller; *H,* Flywheel; *J,* Shunt exciter for generator and motor fields; *K,* Series exciter, separately excited by the main direct-current circuit; *M,* Alternating-current, squirrel-cage induction motor

The detailed scheme of connections for this reversing set is shown in Fig. 210. The control consists of a series of magnetic contactors, some of which are used for reversing the fields, others for changing the resistance in series with these fields, others for purposes which will be described later.

In order to make the generator voltage respond quickly to a change in the controller, it is necessary to wind this field for a low voltage and use a resistance in series with it. If this resistance is short-circuited while the field is being strengthened, it will increase the speed at which the change of flux takes place and therefore hasten the increase in voltage on the generator. This method of manipulating the field is called field forcing. In order to prevent the field from building up beyond the value for which the master switch is set an automatic arrangement is used, shown in Fig. 211. The coils for the contactors, *9* and *10*, controlling the field, are shown as *23* and *24*. These coils are in series with the solenoid *S* which operates the contact mechanism, *30*, and is opposed by solenoid *T*. The strength of *S* depends upon the coils *23* and *24* of contactors *9* and *10* being energized by the master switch. When a contactor is first closed, the coil *S* predominates over *T* and closes contact *30* which energizes coil *25* of contactor *17*. This closes contactor *17* and short-circuits resistance in series with the generator fields. As these fields build up the magnet *T* exerts an increasing pull until the desired voltage is reached, at which point magnet *T* overcomes *S* and opens contactor *17*.



Sequence of Contactors

Sw.	Forward						Off	Reverse					
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3	○	○	○	○	○	○							
4								○	○	○	○	○	○
5	○	○	○	○	○	○							
6								○	○	○	○	○	○
7	○	○	○	○	○	○							
8								○	○	○	○	○	○
9	○	○	○	○	○				○	○	○	○	○
10	○	○	○	○						○	○	○	○
11				○	○	○	○	○	○	○			
12			○	○	○	○	○	○	○	○	○		
13		○	○	○	○	○	○	○	○	○		○	
14		○	○	○	○	○	○	○	○	○	○	○	
15				○	○	○	○	○	○	○			
16		○	○	○	○	○	○	○	○	○	○	○	
17	Gen Field Forcing Voltage Maintainance												
19	Gen. Fld. Disch.												
20	Motor Field Strengthening												

FIG. 210. Scheme of Connections for Reversing Mill Set

This contactor *17* is also used to maintain the generated voltage constant on long passes in the mill. As previously described, the motor-generator set is equipped with a flywheel which by slowing down furnishes the excess power above normal load. But the slowing down of the motor-generator set has a tendency to lower the voltage on the generators if the field strength remains constant. In order to overcome this difficulty and obtain constant voltage which means constant speed of the mill motor, a voltage regulator is used which momentarily closes contactor *17* whenever the voltage drops below normal. The voltage then tends to increase above normal so that by repeatedly closing and opening this contactor, the field has a tendency first to increase and then to decrease, but due to the inductive effect of the field circuit the voltage remains practically constant.

An overload relay is used to limit the armature current. This relay is shunt wound, with as little inductance as possible and is connected across the interpole windings of one of the motors, which acts as an inductive shunt, giving the relay a slight anticipation of a change in the current. But the change in flux in the generator fields has a time lag due to the inductance of the field windings, therefore, when an overload occurs, if we arrest the increase of current in the field windings, the field flux will continue to increase due to this stored energy. An overload relay which inserts resistance in series with the field circuit will not respond quick enough to correct momentary current peaks. It is therefore necessary to add contactor *19*, which short-circuits a section of the resistor in shunt to the field windings; this immediately arrests an increase in flux. The contactor *19* may open and close a number of times during a change in speed. It is found in practice that the various field windings can be timed so that dangerous overloads do not occur except during deceleration when the motors are operating on weakened fields. This overload device is, therefore, arranged so that it operates only when the motors are delivering power to the generators.

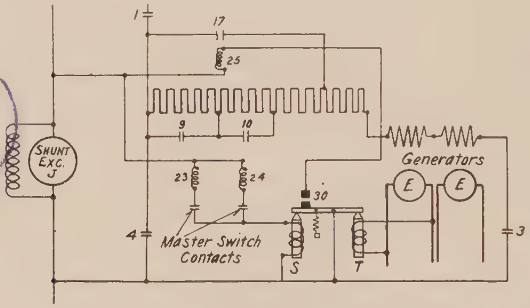


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FIG. 211. Diagram Showing Method of Preventing Field from Building Up Beyond the Value for Which the Master Switch Is Set

The generator field has two sets of resistance in series with it. One set is controlled by contactors *9* and *10* operated by the master switch, for the purpose of regulating the motor speed. The second set of resistance is normally short-circuited by contactor *40*. When an overload occurs it opens contactor *40*, which inserts a resistance in the field, which in turn reduces the current through the armature. Under normal operation this contactor is closed.

The motors have two field windings, one connected to the constant potential source of power exciter *J*, Fig. 209, the other connected to the compound exciter *K*. After the motors have reached normal speed on full field value, the speed may be further increased by weakening the motor fields. This requires the insertion of resistance in both field windings. If the fields are weakened too rapidly during acceleration, excessive current will flow through the armature. Contactor *20* is therefore provided for short-circuiting the resistance in series with the constant potential motor fields. This contactor is controlled by an overload relay, and opens and closes in rapid succession during acceleration, maintaining the armature current practically constant.

If the master switch is operated to decrease the speed of the motors they will regenerate and in doing so reverse the polarity of the field windings supplied from the exciter *K*. This may cause an abnormal weakening of the motor field. To prevent this a reverse voltage relay opens contactor *5* or *6* and disconnects these field windings whenever the motor voltage reverses with reference to the generator voltage without the master switch being reversed. As explained previously, when the master switch is reversed, the polarity of these fields is automatically reversed and therefore the current in these fields is in the correct direction.

The control of the reversing equipment for steel mill service has been given at some length in order to illustrate the nature of the problems arising in such a control system. A more complete analysis of this problem, together with a mathematical discussion, is given in an article by Mr. E. S. Lammers, Jr., presented before the Association of Iron and Steel Electrical Engineers, February, 1920. Some of the problems in this control are similar to problems met with in the control of small adjustable speed motors. As an illustration, contactor *20* which prevents too rapid weakening of the motor field, has its counter part in the ordinary fluttering relay used with adjustable speed motors.

The control equipment for the rapid reversing required in steel mill service differs in some details from the controller used with mine hoists where the change in speed is much more gradual and the motor does not have compound characteristics. The mine hoist controller provides automatic slow down and stop at either limit of travel. This is accomplished by a current relay which reduces the generator voltage to zero at the proper rate to keep the armature current at a constant value.

In order to prevent the generator fields from being disconnected from the line by throwing the master switch to the off position when the motor is still running a voltage relay is used which automatically maintains the generator field circuit and allows the decelerating current relay to slow the set down before disconnecting the fields.

When the generator field is disconnected from the line there is a residual magnetism which causes the motor to rotate at a very slow, creeping speed. This is a desirable feature in steel mill work as the slow turning of the main rolls prevents overheating and consequent injury to the rolls. When applied to a mine hoist this creeping action is very objectionable. It is eliminated by automatically connecting the generator fields across the motor armature in the reverse direction. This causes a small current to flow through the field coils in the proper direction to kill this magnetism.

Steel mills and mine hoists are two of the principal applications using this method of control.

SUMMARY OF CHAPTER XX

The speed of direct-current motors may be controlled by exciting the field at a constant voltage and supplying different voltages to the armature, either from different pairs of several power wires (multivoltage system), or by providing a separate generator for each motor and obtaining different voltages by varying the strength of the generator field (variable voltage system).

Variable Voltage System: By reducing the strength of the generator field low speeds are obtained, by reversing the current in the generator field the rotation of the motor is reversed. The speed and direction of rotation of a large motor may thus be controlled by interrupting or controlling, not an armature current of several thousand amperes, but a field current of perhaps a hundred amperes. A large number of fixed running speeds are thus obtained, with small losses. The speed range may also be economically increased by weakening the motor field in addition to varying the generator field. Dynamic, and usually regenerative, braking is easily obtained. When the generator is driven by an induction motor, the maximum power demand is reduced by adding a flywheel on the shaft of the motor generator set, to absorb or give out energy as required. By means of a slip regulator resistance in the wound secondary circuit of the induction motor is varied automatically with the load: when the power demand is large the resistance increases, allowing the motor to slow down and absorb energy from the flywheel, or return energy to the flywheel by speeding up when the power demand is light (and the resistance decreases). In consequence, an approximately constant amount of power is taken by the motor from the line. The exciter is directly coupled to the shaft of the motor generator set. Since the speed of the motor generator varies and the voltage of the exciter varies with the speed, a voltage regulator is used to ensure a constant voltage (an arrangement simpler, however, than using a separately driven exciter).

Reversing Mill Sets: The stored energy of rotating units increases as the square of the diameter, hence to reduce the diameter and to make easier the reversing of large equipments, as in steel mills, the motor generator set is divided into two units, connected alternately in series (thus, motor, generator, motor, generator) (to avoid the double line voltage otherwise necessary). To avoid reversing heavy series field currents on reversing the motor's rotation, the series field are replaced by windings (variable potential field) excited from a separate generator (series exciter) whose field is in series with the main generator and motor armatures. These windings carry only a small current and are easily reversed when the generator shunt field is reversed. To cause the generator field to respond quickly when the voltage is being changed it is wound for a low voltage (reducing its inductance) and resistance is placed in series with it, which is short-circuited while the field is built up (field forcing). To maintain the generator voltage constant (as on long passes, in steel mills) a voltage regulator alternately inserts and short-circuits a resistance in the generator field. The voltage tends to go above and below normal, but, owing to the inductive effect of the generator field, actually remains practically constant.

By designing the various field windings with appropriate time constants overloads are avoided except during deceleration. For this part of the working cycle an overload relay is operated from a shunt coil connected across a motor interpole (which acts as an inductive shunt giving a slight anticipation of the change in current) and the relay short-circuits resistance in shunt (quicker in effect than one in series) with the field winding, thus quickly arresting the increase in flux. If the motor fields are weakened too rapidly in increasing the speed, the resultant increase in armature current is limited by an overload relay which short-circuits resistance in the motor field, the result being to keep the armature current practically constant during acceleration.

When decreasing speed, the motor may regenerate, reversing the variable potential field. To prevent the total field from being too greatly weakened in this way a reverse current relay disconnects the variable potential fields when so reversed. When the master switch is moved to the off position a voltage relay temporarily maintains the generator field active, assisting in slowing down the set. On disconnecting the generator field a residual magnetism remains, generating sufficient voltage to cause a slow creeping of the motor. In steel mill practice, overheating of the rolls is prevented by the slow turning resulting, but in mine hoists this creeping action, being objectionable, is eliminated by energizing the generator field in the opposite direction sufficiently to kill the residual magnetism (by connecting it across the motor armature in the reverse direction).

CHAPTER XXI

MINE HOISTS

Coal mine hoists—metal mine hoists—contactor controllers—liquid controllers—voltage controllers—safety devices—brakes—automatic control.

Mine hoists may be divided into two general classes: those for coal mines and those for metal mines, the essential difference being that coal mines are shallow and the metal mines deep. Coal mining practice differs in the anthracite and bituminous fields, and the practice varies in different states. In general, hoists for coal mines run from 250 to 1000 horsepower. In metal mines, the motor may reach double the size of that for coal mines. In addition to the main hoists, small hoists are frequently put in for handling men and supplies. These hoists may be so small that the ordinary form of drum controller may be used.

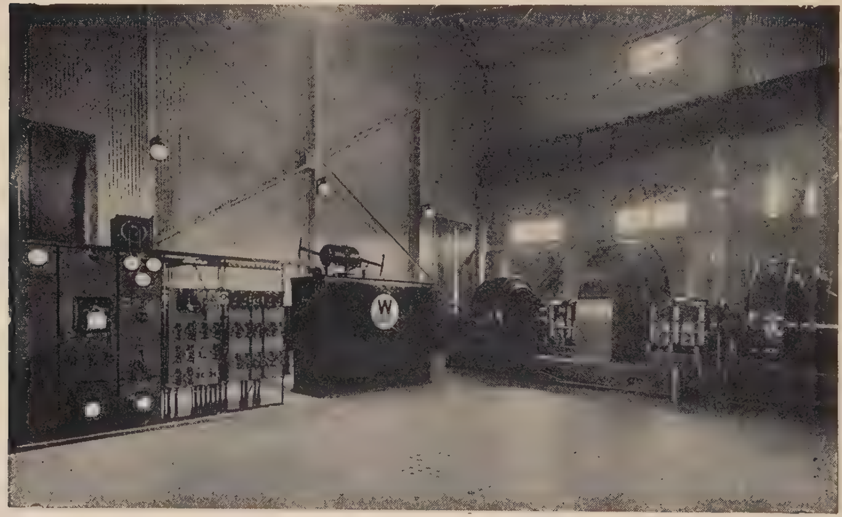

FIG. 212. Hoisting Room for Voltage Control Equipment

Showing the flywheel motor-generator set to the right, the liquid regulator in the center and the control panel at the left. Magnetic contactors are used for varying the strength of the generator field

The large controllers may be divided into three classes:

1. Contactor Controllers.
2. Liquid Controllers.
3. Voltage Controllers.

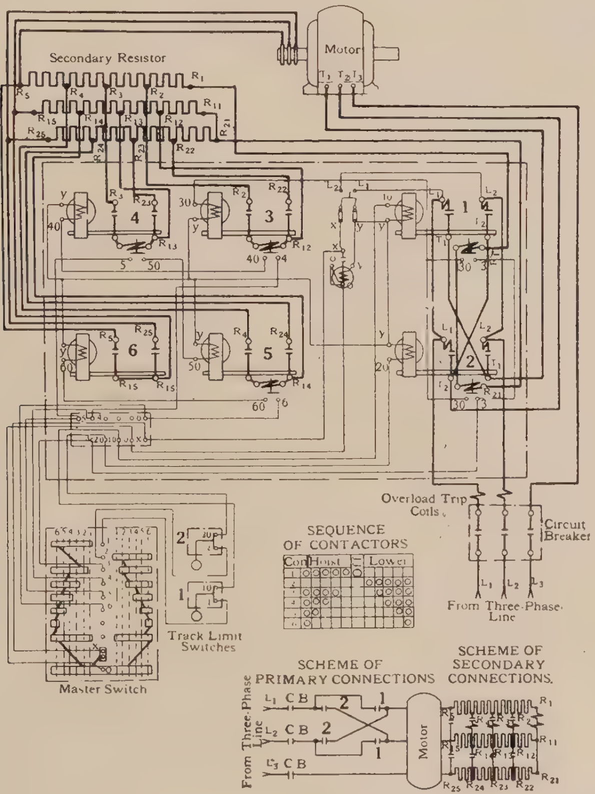

FIG. 213. Diagram of Connections for Contactor Controller

This controller consists of two primary contactors, *1* and *2*, for the purpose of connecting the primary of the motor to the line to give the proper direction of rotation. Four secondary contactors are controlled by current limit relays. These secondary contactors automatically short-circuit the resistor in the secondary circuit of the motor during acceleration. The primary and secondary contactors are controlled by a drum-type master switch. Two track limit switches automatically stop the hoist at either limit of travel. The motor is protected by a three-pole circuit breaker in the supply line

Most mine hoists are operated from alternating-current supply lines and therefore use alternating-current slip-ring motors, either to drive the hoist directly or through a motor-generator flywheel set to supply direct current to the hoist motor. In some cases where direct-current power is available, the direct-current motor which operates the hoist is controlled directly from the supply lines.

CONTACTOR CONTROL

This form of control has been used almost entirely for the smaller motors and also for some of the larger motors up to approximately 1000 horsepower. It is much more durable than the drum controller for small motors and is often preferred, although the first cost is greater. The method of control is illustrated in Fig. 213. The drum type master switch causes the motor to operate in either the hoisting or lowering direction and by changing the position of the handle, the speed of the motor may

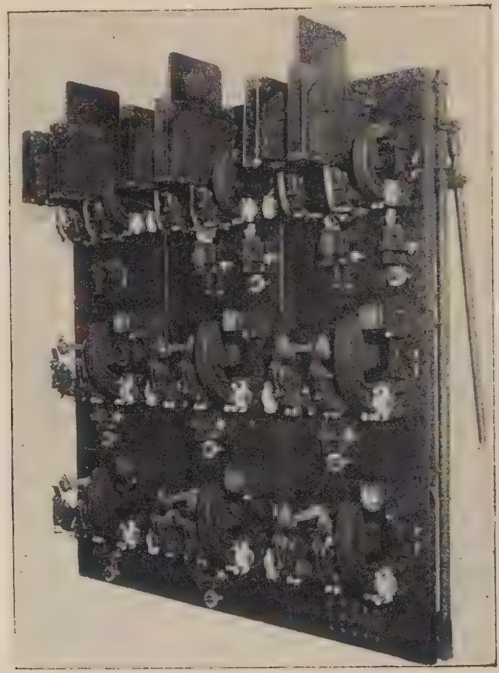

FIG. 214. Contactor Control for an Alternating-current 2200-Volt Motor

Three two-pole contactors are used to control the primary of the motor. One contactor is used for hoisting; a second contactor for lowering, and a third contactor operates for each direction of hoist, acting as an additional safety feature to insure the opening of the motor circuit in case of accident to either of the directional contactors. Six two-pole contactors are used in the secondary circuit. The acceleration is controlled by current limit relays

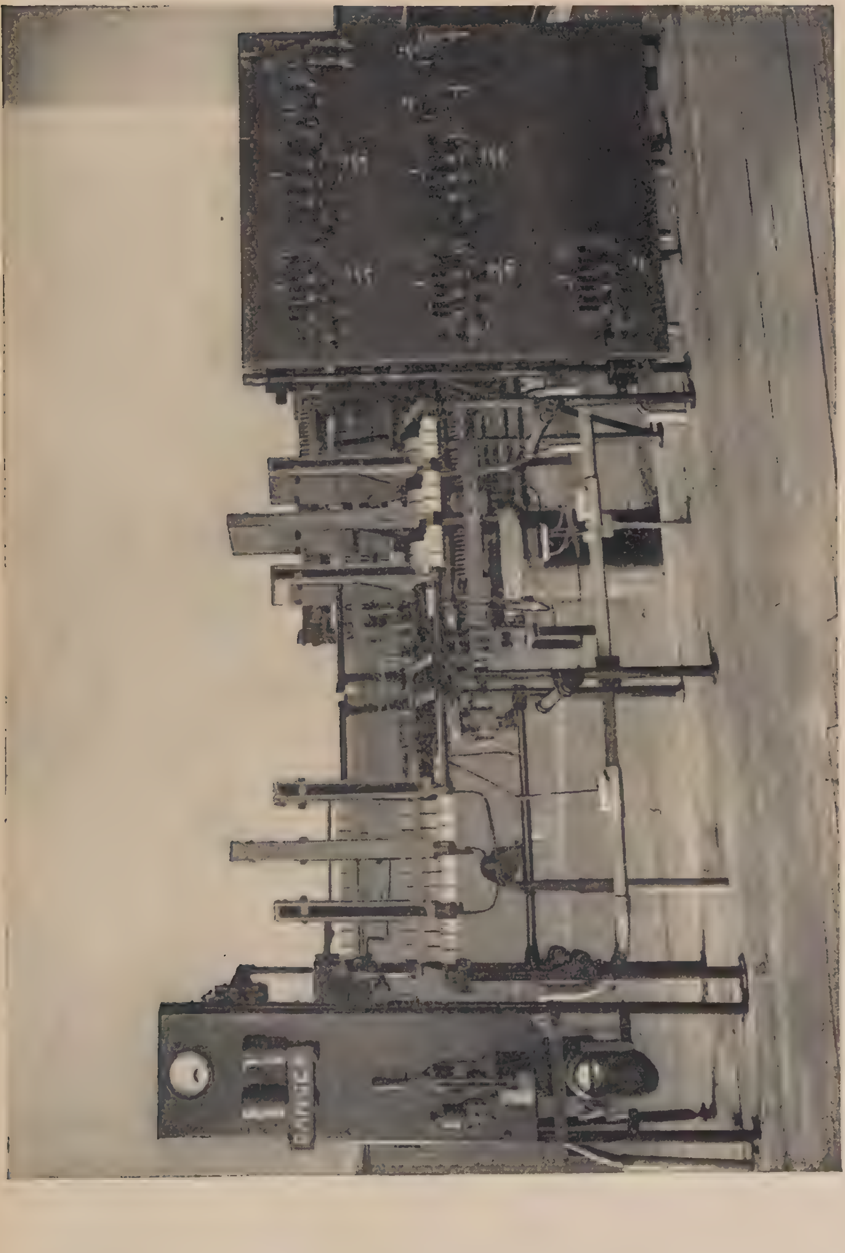

FIG. 215. Installation triple pole. High Voltage Primary Reversing Contactors. Secondary Contactor Panel and Primary Switchboard Panel Operating in Connection with 400 HP., 2200 Volts Induction Mine Hoist Motor

be changed.[1] Ordinarily, a mine hoist is used for the purpose of hoisting material out of the mine. It is therefore operated normally under load conditions and a rheostatic control of this kind gives satisfactory operation. In the off position of the controller, a mechanical brake is applied for stopping the hoist and holding it securely at the landing. This brake is often released by an electro-magnet, which is deenergized in the off position of the controller and applies the brake.

One of these controllers built for a 2200-volt primary and a low voltage secondary is shown in Fig. 214. The primary contactors are provided with large magnetic blowouts to take care of the high voltage. The secondary voltage of an induction motor is determined by the design and is independent of the primary voltage. It is customary to wind the secondary of these motors so that the standard low voltage contactors can be used. The primary may be wound for 220, 440, 550 or 2200 volts. For the larger hoists, a 2200 primary is desirable in order to keep the current small and reduce the size of primary leads.

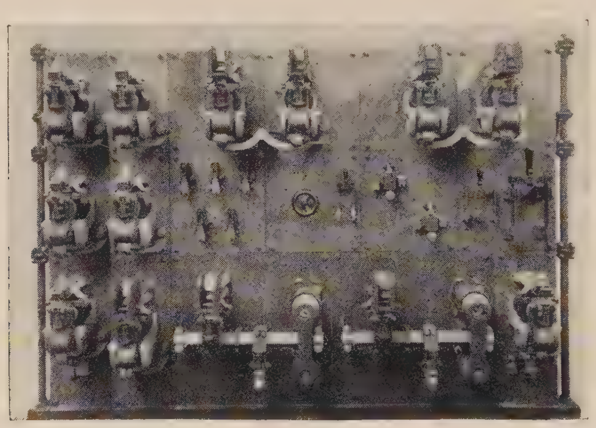

FIG. 216. Contactor Panel for a Direct-current Automatic Hoist

The contactors at the top of the panel, at the right, control the direction of rotation and have a mechanical interlock which prevents one set of contact from closing before the other set is opened. At the bottom of the panel are two contactors with back contacts for slowing down the hoist automatically. The other contactors are used for short-circuiting sections of resistors

When the empty cage is at the top of the hoist and the loaded cage at the bottom, the motor must lift not only the load in the cage, but also the total weight of the rope between the drum and cage. The weight of the two cages usually balances. After the load is started, the rope on the hoisting side becomes shorter and the rope on the lowering side longer, so that the work done by the motor is gradually decreased.[2] In order to assist the motor in starting the load from the bottom, one end of the drum is frequently coned so that the rope is wound on a small diameter at the start, Fig. 217. This works out very well for short travels where the rope can be wound upon the drum in a single layer. For deep mine hoists, the rope is wound back and forth across the face of the drum in layers, which makes it necessary to use a cylindrical drum instead of a cone, so that in deep mine hoisting the load starts with maximum torque.

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[1] The speed-torque curves for this method of control are shown in Chapter XI. These curves show that the speed of the motor depends upon the load.

In bringing the motor to rest, it is sometimes customary to reverse the primary of the motor for a short period of time. This reversing of the motor is known as "plugging." It results in a high secondary voltage. If the motor is running at full speed, the slip of the motor will approximate 200 per cent and the secondary voltage will be double the voltage obtained when the motor is started from rest. If plugging is to be practiced, the secondary control and the insulation of the motor windings should be arranged for this higher voltage. The operator must be careful to turn the controller to the off position when the motor comes to rest after plugging; otherwise, the direction of rotation will be reversed and an accident may result.

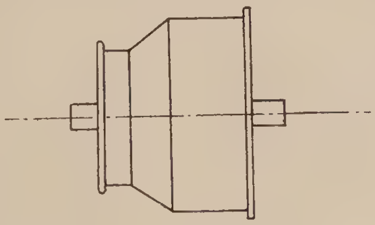

FIG. 217. Coned Drum

The hoist rope starts winding on the small diameter of the drum. As hoisting progresses, it is wrapped around the coned portion of the drum and thence on to the large diameter portion

The present development of the art has not produced a method for obtaining dynamic braking for alternating-current motors, which is applicable to general hoisting requirements. Dynamic braking can be obtained as explained in Chapter XX, by connecting the primary of the motor to a direct-current source of power. This adds some complication which has prevented its general use.

A direct-current controller for an automatic mine hoist, using a 600-horsepower, direct-current motor is shown in Fig. 216. The hoist is operated in much the same way as a skip hoist or elevator. After the motor is started, the load is hoisted to the proper level, automatically slowed down, stopped and the load discharged. The speed of this hoist is 500 ft. per min. Up to the present, such an arrangement has not been installed for use with alternating-current motors. The contactor type of rheostatic control is preferred in some localities to the liquid controller, even for large size motors.

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[2] This is illustrated by the torque curve, Fig. 207.

LIQUID CONTROLLERS

The liquid controller differs from the contactor control in the secondary circuit of the motor only. Both controls use contactors for the primary. The secondary of the motor in this form is connected to a set of electrodes immersed in a solution of water and soda. A cross-section of this control is shown in Fig. 219 and a general view in Fig. 220. The master switch, on the side of the tank, controls the primary contactor and the weir is so arranged that the water level in the electrode tank is at a minimum in the central or off position. The size of this weir is designed so that the electrode tank will empty as fast as the weir is lowered. If, however, the weir is quickly moved to its upward position, it will take from 10 to 15 seconds to fill the upper tank, allowing a suitable time for the motor to accelerate. When the tank is full the secondary of the motor is practically short-circuited, so that the motor runs at approximately full speed. In the reservoir tank underneath the electrode tank is located a system of cooling coils. Water is pumped from this lower tank to the upper tank continuously, causing a circulation around the cooling coils. The height of water in the upper tank is controlled by the height of the weir. The pump is driven by a small induction motor.

FIG. 218. 6600-Volt Controller

An ingenious arrangement of operating levers is illustrated in Fig. 221. This consists of a floor stand having a slot similar to the letter H, one of each of the opposite sides being short. The long sides of the H are for normal operation. If the operator wishes to plug his motor, he moves the handle back in the same slot, passing through the central position into the short side of the slot, which limits the handle so that

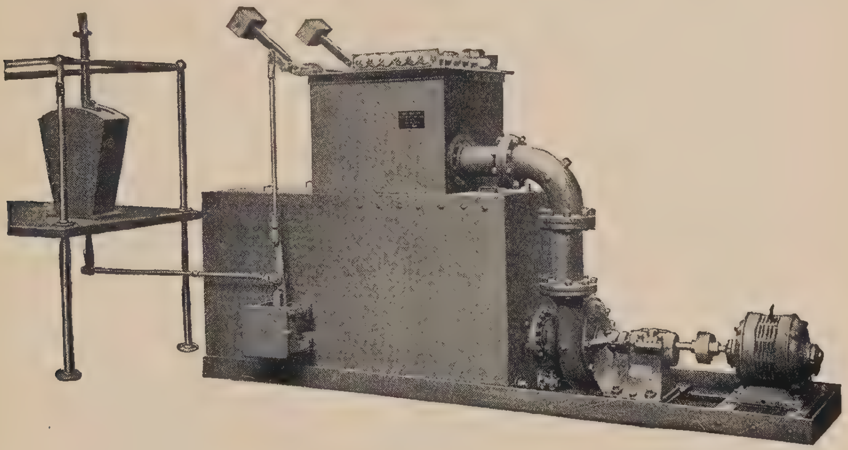

FIG. 219

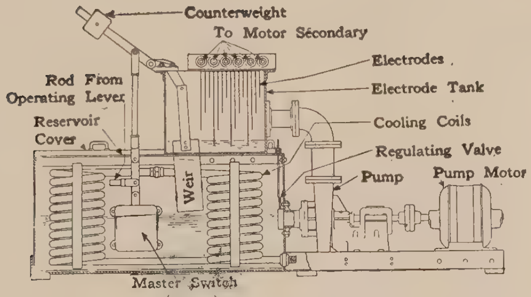

FIG. 220

FIGS. 219 and 220. Liquid Rheostat with H-slot Device

The upper tank contains the electrodes which are connected to the secondary of the motor. The lower tank is a reservoir for the electrolyte and contains the cooling coils. The water is pumped from the lower tank to the upper tank continuously and the height of the electrolyte in the upper tank is determined by the position of the weir. The same levers which raise and lower the weir operate the master switch, which is located on the outside of the reservoir tank. Adjustable stops are provided on the H-slot, Fig. 221, for regulating the depth of the slot for plugging sufficient resistance remains in the secondary circuit to give the maximum torque. To pass from one slot to the other, the handle must be brought to the central position and moved sideways.

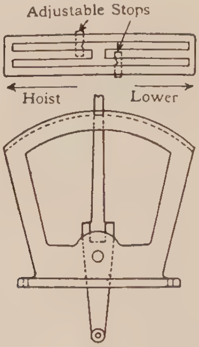

Fig. 221. Single Lever H-slot Device

Compared with the contactor control, the liquid controller has the following advantages:

Simplicity.—There are no electrical connections to get out of order, the only renewals being the addition of fresh water from time to time to replace that lost through evaporation or steaming. Fresh water is all that is required, as the soda in the solution remains constant.

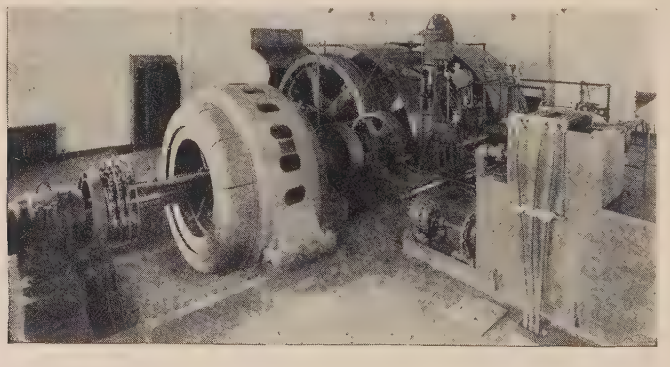

Fig. 222. View of Hoisting Room

Showing operating pulpit and liquid controller. The primary panel is located to the right

Large Thermal Capacity.—The large mass of water will absorb a considerable amount of heat, so that for short intervals of time a large amount of energy can be dissipated.

Overload Capacity.—If energy is accumulated in the rheostat faster than it can be radiated or carried off by the cooling water, steam is formed, absorbing the surplus energy.

No Definite Control Steps exist in this form of controller. It is possible, therefore, to adjust the motor for any desired speed.

The following limitations exist:

Cooling Water Is Sometimes Hard to Obtain and if this water has certain impurities in it, the cooling coils deteriorate quite rapidly. If the water is muddy, it is necessary to blow out the coils from time to time. The problems involved in cooling coils in a controller of this kind are similar to the problems encountered in tubular boilers and condensers.

The Controller Is Harder to Operate from a mechanical standpoint than the contactor type, as the mechanical effort required to move the weir up and down is greater than that required for moving the master switch handle.

The Controller Must Be Located Conveniently to the operating pulpit so that mechanical connections can be made between the lever in the pulpit and the controller.

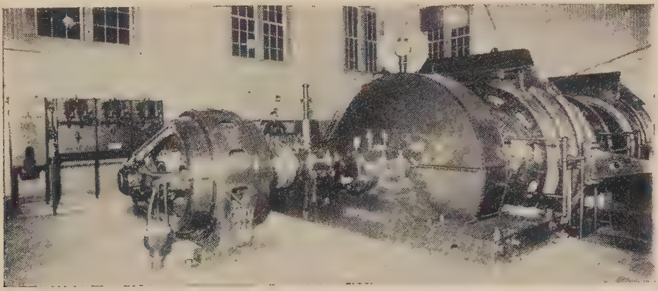

FIG. 223. Hoist Operated by Slip-ring Motor

Showing the 2200-volt hoisting panel, together with the feeder panel in the background

The contactor control is usually cheaper for motors up to 500 horsepower. The liquid controller is often cheaper for the larger motors. This point of difference is not definite, as it changes with variations in design, and is given merely for general information. Other designs of liquid controllers have been used for smaller motors, but the commercial demand so far has not developed the smaller type of liquid controller to any considerable extent.

VOLTAGE CONTROL

This control is particularly well adapted to large hoists for deep mines.[3] Figs. 223 and 224 illustrate installations of this type. The alternating-current power is supplied to an induction motor which drives a flywheel and a direct-current generator. The direct-current generator is connected to a direct-current hoisting motor. The speed and direction of rotation of the hoist motor is controlled by changing the field strength of the generator. The flywheel serves to store energy during the low demand periods and to give out energy when the demand exceeds the average requirements. This is effected by changing the resistance in the secondary of the alternating-current motor, as described in the previous chapter. Hoists using this system of control have the following advantages:

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[3] The principles of this system of control were described in Chapter XX.

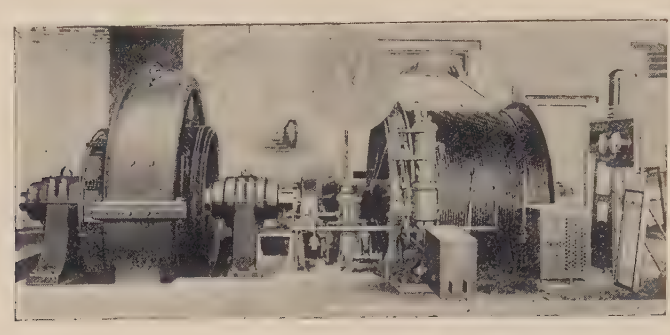


FIG. 224. Hoist Operated by Voltage Control Method

The controller consists of a large field rheostat located on the right hand side of the hoisting drum. The large dial in the foreground is a depth indicator

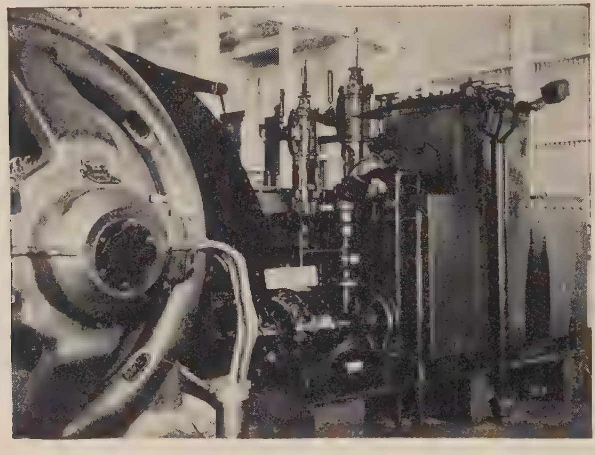


FIG. 225. Liquid Controller Installation

1. The maximum demand for power can be kept close to the average. Where power is purchased on the basis of a maximum demand, considerable saving in the power bill may be effected by the use of a flywheel motor-generator set.

2. The speed of the hoist motor may be controlled closely under all conditions of load. If the hoist is used for lowering men into the mine, the speed of the cage can be held at the proper value and the hoist operated at a high efficiency, as there are no rheostatic losses except in the field control for the generator which is very small. Where the mine is deep, the lowering of the cage on a mechanical brake presents considerable difficulties and it is preferable to use a system having dynamic braking with speed adjustment.

3. Sufficient energy is stored in the flywheel so that one or more trips can be made with the hoist after failure of power. This may be a distinct advantage in case of interruption of the power supply.

4. Where the hoist is in constant operation, the losses of the motor-generator set are less than the rheostatic losses when the motor is operated directly from the supply lines, so that this system gives an economy in power consumption.

The loss in electric power in the hoisting system represents only a part of the total losses. Assuming that an ordinary hoist has an efficiency of 50 per cent and that half of these losses are due to mechanical friction and half due to the electrical machinery and control, we have a possible saving of only 25 per cent of the total power if we operate without electrical losses. If the voltage system of control for any particular installation should show half the loss obtained with a rheostatic control, then the total saving in power would be only 12.5 per cent. Usually the dis-

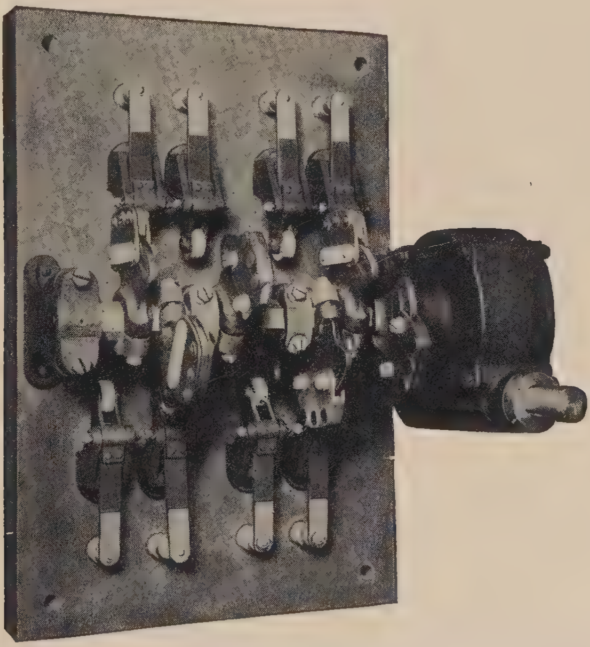


FIG. 226. Cam Limit Switch with Worm Reduction Gearing

tribution of losses is such that the saving is less than this amount. The voltage method of control, comprising a motor-generator set, direct-current hoist motor, flywheel, and slip regulator, will often cost from three to four times as much as the ordinary wound rotor motor with rheostatic control. This difference in first cost must be capitalized against the saving in power. Many installations do not use the voltage method of control on account of its highest first cost. On the other hand, where the operating requirements do not lend themselves readily to rheostatic control, a decision favoring the use of a voltage system of control may be made.

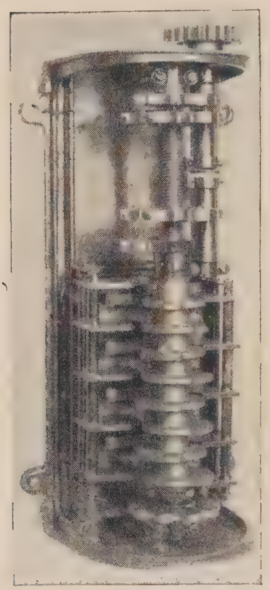


Fig. 227. Geared Limit Cam-type Switch with Traveling Nut

Since the motor-generator set operates continuously, it is not economical to use this system of control where the hoist motor operates infrequently or has considerable periods of rest. If we assume that the periods of rest are approximately the same for a deep or shallow mine it can be readily seen that the ratio of operating time to total time for the hoist motor will vary with the depth of the mine and, the deeper the mine, the more economical it will be to use the voltage method of control.

The mining laws in some localities are much stricter than others and have an influence upon the selection of the proper control for the hoist. Each installation must be carefully studied and the type of control arrived at after reviewing all of the features involved. No general rule can be laid down for the selection of a type control for large hoists.

Safety Devices

Mine hoists, in common with elevators and skip hoists, have definite limits of travel for the car or cage. It is therefore necessary to provide automatic means for stopping the hoist motor as the cage approaches either limit of travel. Where the speed of the hoist is considerable, it is necessary to slow the motor down before the final stop. This slowing down may be accomplished by gearing limit switches to the drum shaft of the hoist or by a centrifugal device which stops the hoist if the operator exceeds a certain speed as he approaches either limit of travel. For high speed hoists, the latter method seems to be preferable. This centrifugal device consists of governor balls revolved at a high speed by means of mechanical drive from the hoisting machinery. These balls are mechanically connected to a latch which is raised or lowered, depending upon the speed of the hoist. Passing underneath this latch is a cam driven from the hoist. The height of this cam is changed at either limit of travel and so adjusted that the cam will come into mechanical contact with the latch if the speed exceeds a fixed amount at any part of the travel. If the cam engages the latch, a contact is opened which disconnects the hoist motor from the line and applies the brakes. This will usually stop the hoist short of the landing and it will be necessary for the operator to reset the device by hand before it can proceed.

A geared limit switch consisting of a series of cams is shown in Fig. 226. The cam shift is driven from the hoist mechanism. These cams can be set to open their corresponding switches for various positions of the cage. This limit switch usually has several notches, the first providing a slower motion for the hoist and the last one disconnecting the motor from the line and applying the brake. If a centrifugal stop is used in conjunction with the geared limit switch, the geared switch may be used only for the final stop.

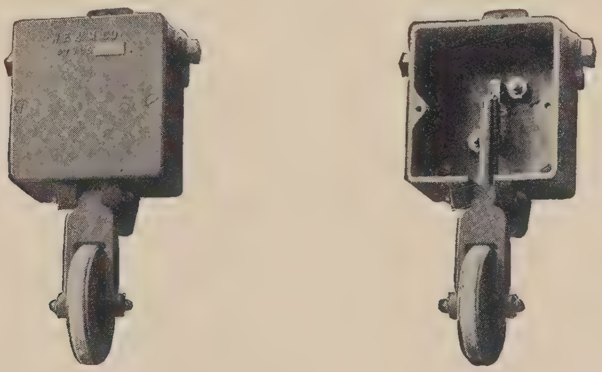


Fig. 228. Hatchway Limit Switch with and without Cover

A track limit switch which is placed in the runway for the cage and arranged to be tripped when the cage reaches this part of the travel is shown in Fig. 228. Two of these switches are used, one in the runway for each cage, and they are placed so that they will not operate if the general limit switch performs its functions properly and constitute an extra safety stop. When only one cage is used, a single limit stop at the top travel of the cage is usually sufficient.

BRAKES

A small hoist may be provided with a friction brake released by a magnet and applied by a spring or weight. This brake is applied on failure of voltage or when the controller is in the central or off position. It may be applied also by any of the limit stops. For larger hoists, a more elaborate system of braking is necessary. One of these systems uses oil under pressure for operating the brakes. The oil is controlled ordinarily by a lever in the operating stand. In addition, a magnetic valve is so arranged that when the magnet is deenergized, the brake is applied. This magnet can be disconnected from the line by the centrifugal stop, the geared limit switches, the track limit switch or any other safety means available.

AUTOMATIC CONTROL

The question of controlling hoists so that they automatically stop at either limit of travel and discharge their load, has been considered from time to time, but very few are in use. The control shown in Fig. 216 illustrates one of these hoists. At present direct-current hoist motors should be used. By using the voltage method of control, large motors can be made to slow down and stop automatically. It has been a question, however, whether enough would be gained by this automatic operation to pay for the additional complication. Ordinarily, the stretching of the rope in a deep mine hoist would frequently put such a device out of adjustment. The longer the rope, the greater the difficulty from this source. For shallow mine hoisting, this difficulty is not so serious. The time will probably come when there will be considerable use made of automatic stopping and discharging of the load from shallow hoists.

SUMMARY OF CHAPTER XXI

Deep (metal) mines may require a hoist motor and control double in size that of a shallow (coal) mine (ranging from 250 to 1000 horsepower). For small hoists drum type controllers may be used, for large hoists, the contactor, liquid, or voltage type.

CONTACTOR TYPE CONTROLLER: The contactor type controller is more durable though more expensive than the drum type and has been successfully applied to motors up to 1000 horsepower in size. Motors wound for high voltages are often preferred since smaller currents are carried and smaller leads may be used. The primary contactors of high voltage controllers have large magnetic blowouts to take care of the high voltages. The motor secondary, however, is usually wound for a low voltage and standard contactors are used in the secondary circuit.

When the rope forms a single layer upon the winding drum the motor load may be equalized during the lift by using a cone-shaped drum. The increase in load due to the length of rope between the motor and the loaded cage at the bottom at starting is compensated for by permitting the motor to begin winding the rope on the small end of the drum. For deep mine hoists the rope forms more than one layer on the drum and this scheme is not feasible but the motor must exert its maximum torque at the start. If stopping the motor by plugging (throwing the master switch from the full speed forward to the full speed reverse position) is practiced the insulation of the secondary winding is subject to doubled voltage and should be designed accordingly. At the present time dynamic braking for a-c. motors has not been found practical.

Liquid Type Controller: The primary control of the liquid controller is similar to that of contactor controllers but the motor secondary is connected to electrodes immersed in water and soda, the immersed area of which is varied by lowering or raising the level of the solution by means of a weir, the resistance being increased or decreased and the motor slowed down or speeded up accordingly.

Plugging is permitted by operating the controlling lever in one branch of an H-shaped slot for forward movement and in the other for reverse movement, adjustable stops in each branch determining the position of maximum torque when plugging.

The liquid controller is simple, has large thermal and overload capacity, and from the absence of definite control steps smooth acceleration and any desired speed may be obtained, but in some locations clean cooling water is hard to obtain, and the controller requires more manual effort to operate and must be located close to the operator's pulpit. In sizes less than 500 horsepower it is more expensive than contactor control.

Voltage Type Controller: Voltage controllers are well adapted to deep mine hoists, their advantages being that (1) the power demand can be kept close to the average; (2) the speed may be controlled closely; (3) in the event of power failure the stored energy in the flywheel permits one or two additional trips to be made. For constant operation they are more economical than rheostatic control but their cost is three or four times greater and hence they may not prove economical where the operation is infrequent.

Safety Devices: The hoist is slowed down before reaching the final stop by limit switches geared to the hoist drum shaft or by a centrifugal device. The latter consists of governor balls which raise or lower a latch to engage with a cam driven from the hoist. If the motor overspeeds the latch engages the cam; when the hoist approaches either limit of travel the cam approaches the latch; in either case a contact being opened which disconnects the motor and applies the brakes. The geared limit switch is a shaft geared to the hoist mechanism, bearing cams set to open switches at various positions of the cage. Hatchway limit switches may also be used, placed in the runway of the cage and tripped by the cage at a certain point in its travel.

A friction brake may be used, released by a magnet and applied by a spring or weight, or for large hoists an oil brake may be used in which the brake is operated by oil under pressure.

Automatic stopping and discharging of the load has been used for shallow hoists by the stretching of the rope in deep mine hoists renders automatic operation difficult.

CHAPTER XXII

HYDRAULIC PUMPS

Centrifugal pumps—positive acting pumps—control systems—pressure regulators—float switches—elevator pumps—pumps in municipal plants—pumps in irrigation service.

There are two types of hydraulic pumps in general use, one known as the centrifugal type and the other as the positive acting type. Positive acting pumps are usually of the piston or plunger design.

Centrifugal Pumps

A centrifugal pump consists of a rotating set of vanes known as the "impeller," located within a water-tight housing. The water enters at the center of the impeller and is discharged from the periphery. The pressure of the water depends upon the revolutions per minute and the diameter of the impeller. The high head centrifugal pump was not a success with the ordinary type of reciprocating engine; it is, however, particularly well adapted for steam turbine and electric motor drive. Large outputs can be obtained from a relatively small pump, on account of the high speed of operation. The high speed also reduces the weight of the motor for a given horse-power output. The flow of water is continuous, eliminating pulsations which are often objectionable.

Positive Acting Pumps

These pumps consist of a cylinder with either a piston or a plunger. A given amount of water is pumped for each stroke of the piston or plunger. The total volume of water is therefore proportional to the number of strokes of the pump. These pumps are well adapted for the ordinary reciprocating steam engine. When pumps of this type are driven by an electric motor, it is necessary to gear the motor to a crank shaft in order to convert the rotating motion of the motor into the reciprocating motion of the pump. This type of pump is well adapted for high pressure work but is being largely displaced by the centrifugal pump for ordinary use.

When a positive acting pump is connected to a long discharge pipe considerable work is done in accelerating this column of water from rest to the proper velocity. The effect is somewhat similar to a heavy flywheel on the motor shaft. In applications of this kind, care should be taken to provide a controller of sufficient capacity for accelerating a load with this large amount of inertia.

Small pumps of both kinds are in general use. Many sizes and types can be seen in ordinary hotel or office buildings, and often in private houses. They are used to pump drinking water and for the sanitary system. Some pumps are used where the basement level is below the natural drainage level; requiring the drainage water to be lifted before it can be delivered to the sewage system. Larger pump installations may be found in industrial plants, towns and cities for supplying the water required for these establishments or communities. Many of these pumps are now driven by electrical motors.

Central station service is replacing many of the isolated power plants in buildings and industrial establishments. The advantage of a central station supply of electric power is obvious. The cost of this power is usually less and most of the space occupied by the private power plant can be used for other purposes. This general use of central station power is increasing the number of electrically-driven pumps. Where pumping is done on a large scale, arrangements can often be made to do this pumping at the "off peak" time, in this way using the central station equipment to better advantage and exceptionally low rates may be obtained. This utilization of off peak power is very attractive to the central station and is well worth considering by anyone intending to pump water on a large scale. Even where the pumping must be continuous throughout the twenty-four hours, the power requirements are fairly uniform and good rates can be obtained on account of this uniformity of demand.

System of Control

Small pumps driven by squirrel-cage motors can be started by connecting the motor directly to the line. Only a primary switch is required. Large motors may use an autostarter where they are started and stopped infrequently. For frequent starting and stopping, a slip-ring motor or a compound direct-current motor should be used. For direct-current service, the compound-wound motor gives the best results for either centrifugal or plunger pumps. For the two latter types of motors, an ordinary non-reversing rheostatic control is used consisting of a line switch for connecting the motor to the circuit, and one or more contactors for short-circuiting the starting resistor. The line switch is usually provided with an overload relay or, if the control is manually operated, the line switch may be an ordinary circuit breaker. Low voltage release is usually supplied with automatic control, as it is desirable to have the motor start automatically upon re-establishment of the power circuit after an interruption. The master switch may consist of a push button or, where speed regulation is desirable, a drum-type master switch can be used. It is usual, however, to start and stop pumps automatically. The automatic means may be actuated by pressure or by the height of the water in the reservoir or tank; the latter is known as a "float switch."

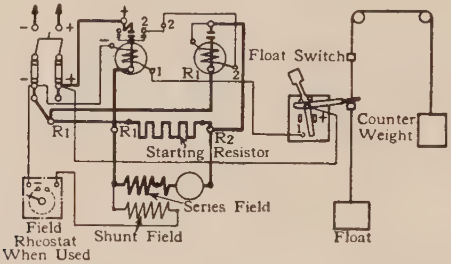


FIG. 229. Connections of a Two-point Direct-current Automatic Controller, Operated by a Float Switch

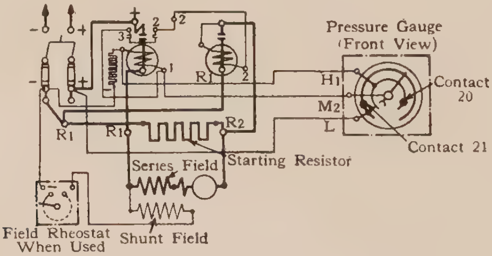
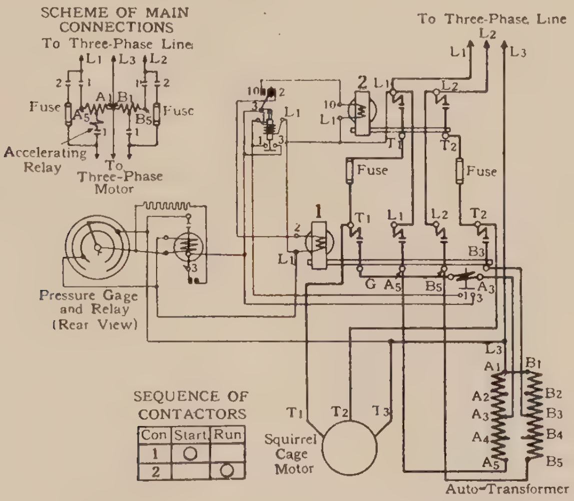


FIG. 230. Connections of a Two-point Direct-current Automatic Controller, Operated by a Pressure Gauge

PRESSURE REGULATORS

Two general forms of pressure regulators are used, the "Bourbon gauge" and the "diaphragm" type. The gauge type consists of the ordinary indicating pressure gauge with a contact make-and-break device attached to the indicating needle, Fig. 232. Some modifications in the standard gauge are required for the addition of this contact device. In order to reduce the arcing at the contact points, a relay is used. This relay is connected so that, when it closes, it bridges the low pressure contact on the pressure gauge and prevents an arc at this contact when the gauge needle moves to a higher pressure. The high-pressure contact is arranged for short-circuiting the coil of this relay, which immediately opens the relay, and at the same time opens the circuit through the gauge contact. By placing resistance in series with the relay coil, this short-circuiting can take place without danger of excessive current.



Con	Start	Run
1	○	
2		○

FIG. 231. Diagram of Connections of an Automatic Autostarter

For a squirrel-cage motor operated by a pressure gauge

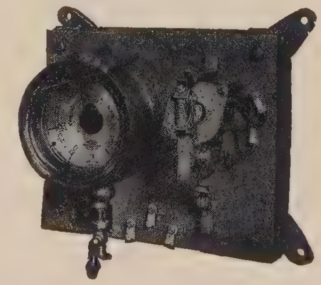


FIG. 232. Gauge Type Pressure Regulator

The diaphragm regulator consists of a metal diaphragm having pressure on one side and a weight or spring on the opposite side. The diaphragm raises or lowers, due to variations in the water pressure. This movement of the diaphragm mechanism closes or opens the contacts of the master switch. The diaphragm regulator ordinarily does not require a relay, as the contacts are large enough to take care of the control circuit of an ordinary size contactor.

When a pressure regulator is used with a positive acting pump, it should not be connected directly to the pump delivery as the pulsations cause the regulator to open and close the contacts in rapid succession and give very poor results. Usually the pump delivers to the pressure tank or standpipe, and the pressure regulator can be connected to the tank or standpipe. Where the pump delivery is long and it is not convenient to connect the pressure regulator in this way, special precautions should be taken to prevent the regulator from being oscillated by the pulsation in the pump delivery.

Float Switch

This master switch consists of a small contact which is opened or closed due to a difference in level of the water in the tank or reservoir.

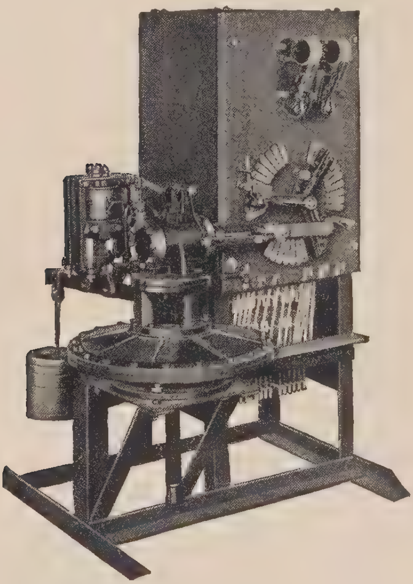


Fig. 233

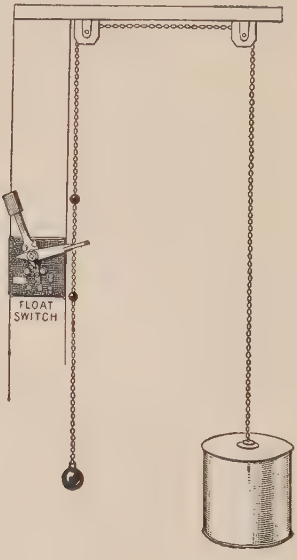


Fig. 234

Fig. 233. Regulating Controller in Connection with a 13-HP., 220-Volt, DC. Motor Made Possible a 55 Per Cent Reduction in Current Required

Fig. 234. Open Type Float Switch

One form of this switch is shown in Fig. 234. The contacts are provided with a quick make-and-break arrangement so that the slow movement of the float does not cause arcing. This float switch is connected to the pilot wiring of the controller and serves to start and stop the motor, due to variation in the water level. If this float switch is used in a reservoir where large waves are apt to occur, it should be mounted in an enclosed compartment to protect it from the wash.

SPECIAL APPLICATION

The foregoing statements are general and in the main, apply to small installations. Larger installations and special applications should be given particular consideration in order to obtain good results.

ELEVATOR PUMPS

Among the special applications may be mentioned elevator service. Hydraulic elevators are usually operated in banks comprising several elevators connected to a single pressure tank. The elevators discharge into an open tank and the pump takes the water from the open tank and delivers it to the pressure tank. For large installations, several pumps are used. The pumps are controlled by pressure regulators which start and stop the pump for variations in pressure. During some portions of the day, the pump is operated at infrequent intervals, as the elevator service is light. At other times, particularly the noon hour and closing hour in the evening, office building elevator pumps are started and stopped quite frequently, sometimes two or three times a minute, entailing a considerable shock upon the system. One method of overcoming this difficulty is to slow the pump down, rather than to stop it when the pressure reaches a predetermined value. If a positive acting pump is used, considerable power may be lost by such an arrangement, as the water pumped is directly proportional to the speed of the pump. To reduce the output one-half, the pump must operate at half speed, which causes a loss in resistance equal to half the electric power delivered to the motor. If centrifugal pumps are used and designed for this service, a small change in speed will make a large change in water delivery. The curves, Fig. 235, represent the gallons of water delivered by a typical pump with reference to the speed of the pump. This shows that a small reduction in speed makes a large difference in the output, and that therefore, by in-

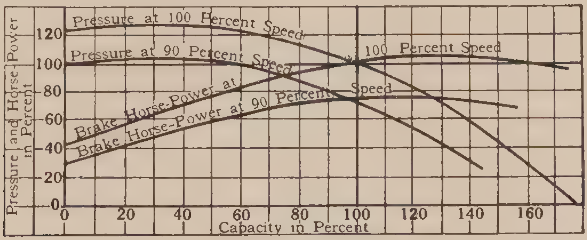
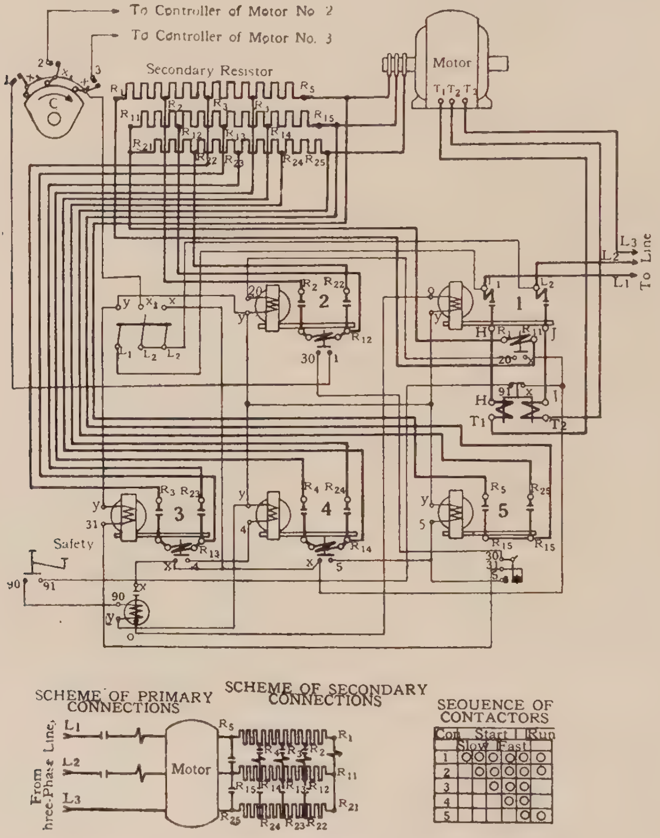


FIG. 235. Typical Capacity and Horsepower Curves of a Centrifugal Pump Showing the effect of a ten per cent speed variation

serting a small amount of resistance in the motor circuit, the output of the pump can be materially decreased with only a small loss in the re-


To Controller of Motor No. 2
To Controller of Motor No. 3
Secondary Resistor
Motor
To Line
Safety
SCHEME OF PRIMARY CONNECTIONS
SCHEME OF SECONDARY CONNECTIONS
From Three-Phase Line
Motor
SEQUENCE OF CONTACTORS

Con	Start					Run
	Slow				Fast	
1	○	○	○	○	○	○
2		○	○	○	○	○
3			○	○	○	
4				○	○	
5					○	○

FIG. 236. Connections of a Wound-secondary Induction Motor for a Large Elevator Installation

On closing the knife switches in the control circuits of the three motors, contactors *1* and *2* on each panel operate in succession, starting up the motors and accelerating them to somewhat less than full speed. If the pressure is low, contacts X_1 on the regulator *C* (shown in detail in Fig. 237) are automatically closed, accelerating motor No. 1 to full speed and then, if needed to maintain the pressure, No. 2 and No. 3 in succession. If the pressure gets too high, motor No. 3 is slowed down and if pressure still stays high, motors No. 2 and 1 are then decelerated by the regulator. It is necessary to keep all the motors running all the time that the discharge valves are open, in order to maintain pressure on the centrifugal pumps

sistance. Assuming a ten per cent reduction in speed, only ten per cent of the input of the motor will be wasted as heat in the resistance. The horsepower curves show a material reduction in horsepower input with a ten per cent reduction in speed, so that the loss represents considerably less than ten per cent of the full-load input of the motor. The curves showing the relation in percentage between the pressure and gallons of water delivered, indicate that at a small increase in pressure above normal the pump ceases to deliver water. If, however, the pressure drops below normal, the amount of water delivered materially increases. This feature of the centrifugal pump tends to make it self-regulating.

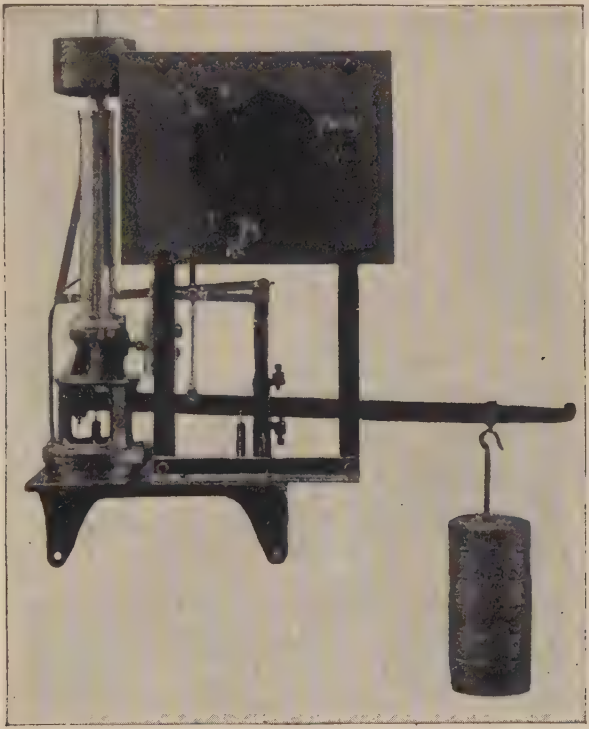


FIG. 237. Diaphragm Pressure Regulator

For controlling three motors. This regulator consists of a diaphragm balanced by weights to operate at the proper pressure. The diaphragm actuates a pilot valve which admits pressure to the vertical cylinder or connects the vertical cylinder to the discharge mains, depending upon whether the pressure is high or low. The movement of the piston in this vertical cylinder operates a cam which opens and closes the electrical contacts by means of small cam switches. The position of these cam switches is adjustable so that three pumps can be arranged to be started or accelerated in succession as the pressure falls, and to be disconnected or slowed down as the pressure rises

Fig. 236 shows a connection diagram and Fig. 237 the regulator used with three slip-ring motors for a large elevator installation. The regulator varies the speed of the motors, one after another, as the pressure varies.

MUNICIPAL PLANTS

Motor-driven centrifugal pumps[1] are used with considerable success for pumping the service water for municipalities where central station power is available. Two systems are used: (1) Reservoir system, (2) direct pumping into the service mains. Where the reservoir capacity is sufficient, the pumps may be worked during the night using power at the "off peak" time, thus securing exceptionally good rates and providing a very attractive load for the central station. Usually the water is delivered at 60 to 100 lbs. pressure for ordinary purposes. In the event of a fire, additional pumps are connected in series with the existing pumps to increase the pressure to 100 or 200 lbs. in a restricted district. Some municipalities have a separate set of mains for fire purposes, and electrically-operated fire pumps maintain a constant pressure on these mains by means of automatic regulators.

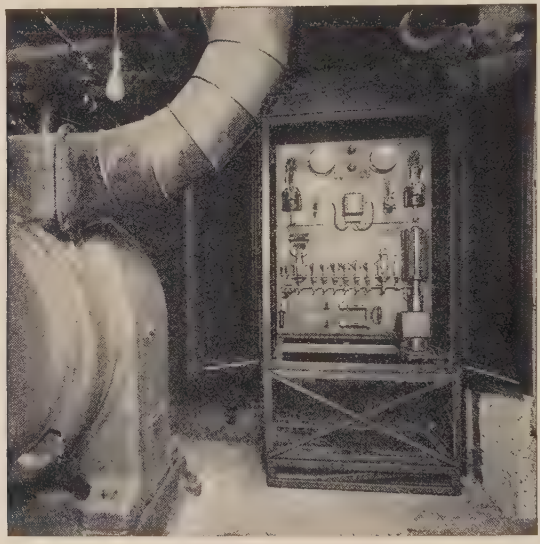


FIG. 238. Fire Pump Starter Arranged for Automatic and Manual Operation

Where the water is pumped directly into the service mains without reservoir capacity, the centrifugal pump can be designed with a flat delivery curve, so that it automatically regulates the volume of water, depending upon the demand. This can be seen by referring to Fig. 235. With the motor operating at a constant speed the water delivery varies from zero gallons at the maximum pressure to considerably more than the full output of the pump at reduced pressures. If judgment is used in connecting in the proper number of pumps, pressure can be maintained close to the average value and the pumps operated with fair economy.

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[1] See article by Mr. R. L. Yates, *Electric Review,* March 16 and 23, 1918, which discusses the hydraulic problem in considerable detail.

The argument is often raised that the turbine-driven centrifugal pump will give greater efficiency for varying amounts of water delivered, as the speed can be automatically controlled by a regulator. While this statement is true, it must be remembered that the losses in the steam generating plant are considerable when only a small amount of power is used. The stand-by losses in piping and other equipment forms quite an item of the total loss. A steam generating equipment, consisting of boilers together with the auxiliary equipment required for operating them, represents considerable initial cost and requires the services of several experienced men, whereas a single engineer and attendant are sufficient to operate a large electrically-driven installation.

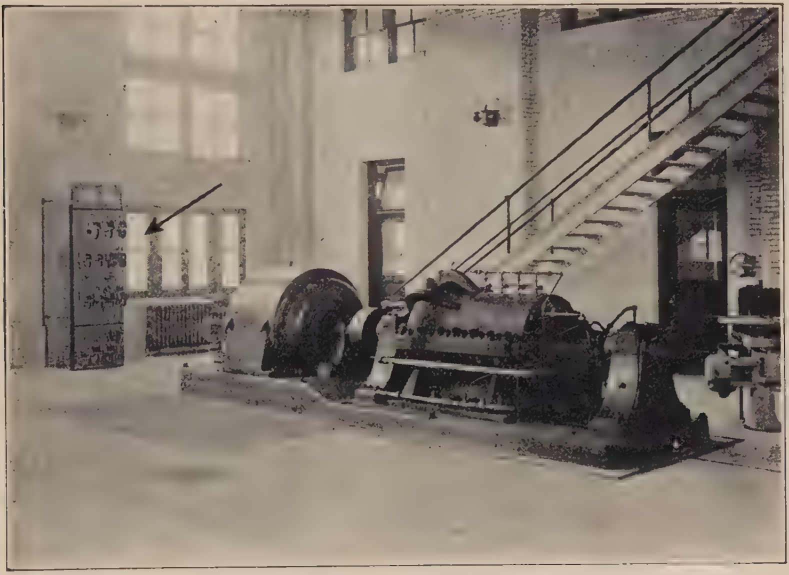

Fig. 239. Automatic Controller Used with Motor-Driven Pumping Unit on High Pressure Fire Service

Where steam power is already installed and used for other purposes, steam-driven centrifugal pumps may prove advantageous. On the other hand, if central station power is available at a reasonable rate, the first cost and the maintenance of electrically-driven pumps will be much less than for corresponding steam-driven pumps with other boiler house equipment. It is therefore evident that the electrically-driven pump has a considerable field of application for municipal pumping. In addition to the supplying of service water, electrically-driven pumps are often necessary to provide for a suitable drainage system. These pumps are installed in sump basins located at convenient points in the drainage area. On account of the scattered location of these pumps, electric power is used. A float switch can be arranged to start and stop these pumps with a given variation of level in the sump pits.

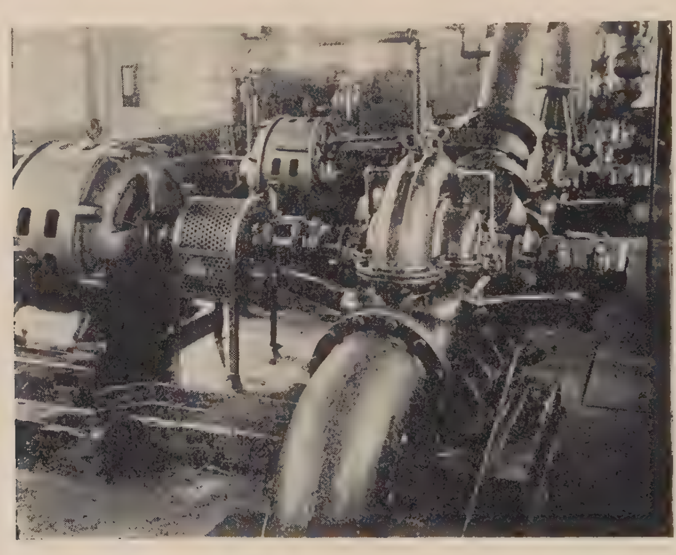

Fig. 240. Typical Motor-operated Centrifugal Pumps

The motors are rated at 150-hp., 2200 volts and the pumps have a capacity of 3000 gallons per minute at 115-foot head

Irrigation

The electrically-driven pump is the only solution for pumping water for irrigation purposes. Irrigating pumps must be located at various points scattered over a wide area. Power is usually transmitted at high voltage to suitable substations which supply pumps for a given area. In certain sections of the country the water is obtained from wells, each property owner operating one or more pumps. The limitation to this method of distribution is the expense of changing from the high voltage transmission lines to a low enough voltage to operate the small pump motors. Where this difference in potential is very great, the expense of a stepdown equipment is a considerable item. By combining the substations, the cost of this stepdown equipment can often be materially reduced. This limitation in stepdown equipment is one of the difficulties now experienced by power transmission companies in supplying electric power to farmers and other small users adjacent to their transmission lines.

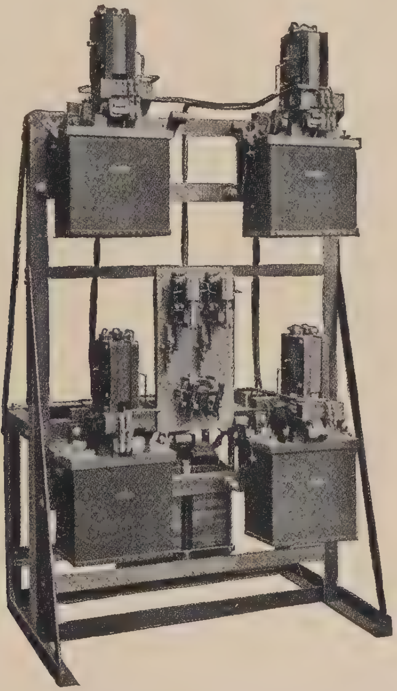

FIG. 241. High Tension Automatic Motor Starter, with Oil-immersed Switches. Time Limit Acceleration

SUMMARY OF CHAPTER XXII

Electrically-driven pumps are usually of the centrifugal type and operated at comparatively low pressures, although centrifugal pumps can be built for several hundred pounds pressure when necessary. The use of central station power reduces the first cost and space requirements for such an installation. The operating costs also are reduced, as one attendant can often maintain several pumping stations where automatic control is used. Where pumps are scattered over a considerable area, electric drive is the only solution, as it would be out of the question to distribute steam power to scattered pumps. Where steam power is available, such as in boiler rooms, the feed pumps have been usually operated by steam. Centrifugal pumps, driven by electric motors, are well adapted for large pumping installations, such as are used by municipalities and large industrial works. Where hydroelectric power is available, electric service for pumping during the "off peak" period is usually much cheaper than steam power.

CHAPTER XXIII

BRAKING OF ELECTRIC MOTORS

Methods of braking an electric motor—friction braking—dynamic braking—brake shoes—brake wheel—adjustments for wear—magnetic armature type—plunger type—mechanical structure of brakes—dynamic braking—allowing for machinery friction.

The previous chapters have dealt with methods of accelerating the motor from rest to full speed. In this chapter we shall discuss means of stopping the motor, commonly called braking. There are two general methods employed:

(1) friction braking;
(2) dynamic braking.

The type of friction brake usually employed for electric motors is known as a magnet brake. It consists of a friction member held against the brake wheel by a spring or weight and released by a magnet. The various commercial designs of this brake are shown in Figs. 242, 243, 244 and 245. The releasing magnet may be designed for either direct current or alternating current. The alternating-current magnets are always shunt wound. The direct-current magnets may be either series, shunt, or compound wound, depending on the application. Most direct-current magnet brakes are shunt wound with series coils. The heating characteristics of these coils should be the same as the series coils of the motor with which they are used. The most common applications for these series-wound brakes are cranes and hoists. The coil is connected in series with the motor armature and releases the brake shoes as soon as current is supplied to the motor. The shunt-wound brake is applied to elevators and a few other applications where the load on the motor varies over a wide range.

The alternating-current magnet brake is always provided with a shunt coil. This coil may be connected across two of the primary circuits of a wound secondary induction motor so that it will release whenever the motor primary is energized. This arrangement cannot be used with squirrel-cage motors if a reduced voltage is used in starting. In this case a separate switch is required for the brake coil.

A mathematical discussion of the stored energy of a rotating body such as a motor armature or a moving load such as a hoist can be found in any textbook of mechanics.[1]

The design of a magnet brake may seem to be a simple one. In practice it has been found quite difficult to make a brake embodying all of the desirable features. A brief discussion of some of the elements entering into this design will be of interest.

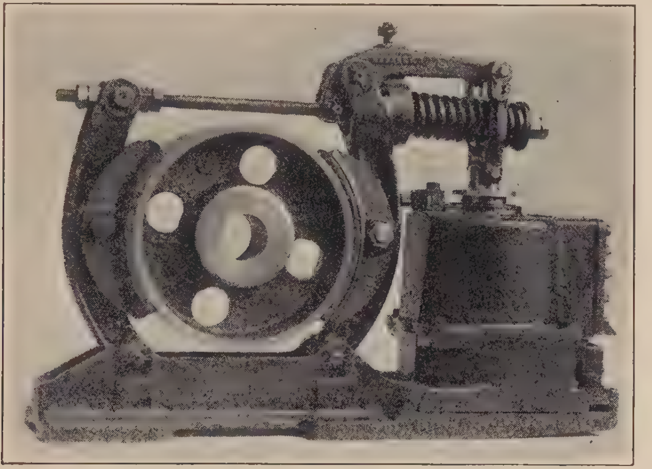

FIG. 242. Magnet Brake (Shoe Type)

BRAKE SHOES

Experience has shown that the shoe type brake is the design best adapted for general applications. The brake shoes are provided with a lining that can be renewed from time to time. This lining should have a constant coefficient of friction over a wide range of speed and should not be affected by moisture or a small amount of oil that might get on the brake wheel. This lining should be a good conductor of heat and the coefficient of friction should not be seriously affected by any operating temperature. The best form of brake lining now available consists of asbestos and rubber interwoven with copper wires. This lining is usually riveted to a cast iron shoe, the whole shoe being removable in order that the lining may be replaced.

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[1] A concise explanation of these formulas is given by Mr. E. M. Bouton in his article on the braking of electric motors in the May, 1918, issue of the Electric Journal, page 168.

BRAKE WHEEL

The diameter of the brake wheel should be kept small in order to reduce its stored energy and to keep the fiber stresses in the rim within safe limits. The stored energy represents a direct loss as the brake must absorb this energy in addition to stopping the motor armature and load. The outer fiber stress enters as a factor in wheels of large diameter and in some cases makes it necessary to use steel wheels. The series motors with which these brakes are used are guaranteed to operate at a speed considerably above normal without mechanical injury to the armature. The brakes used with these motors must have the wheels so designed that there will be no danger of bursting when operating at the maximum guaranteed speed of the motor.

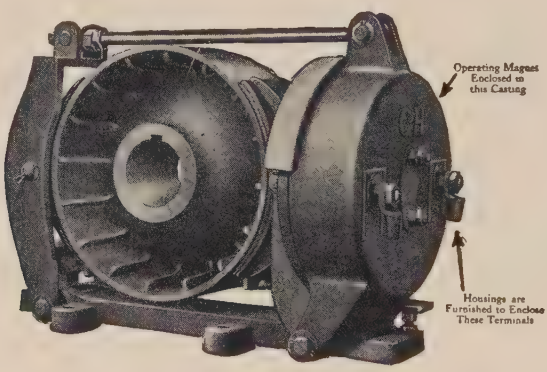
Operating Magnets Enclosed in this Casting
Housings are Furnished to Enclose These Terminals

FIG. 243. Magnet Brake (Shoe Type)

Another limitation in the size of the brake wheel is the distance between the motor shaft and the motor feet. When separately mounted it is desirable to have the brake wheel small enough to permit mounting the brake on the same foundation level as the motor. Brakes that are attached to the motor should have their mechanical parts designed so that they will clear this foundation line.

These limitations fix the maximum diameter and weight of the brake wheel. On the other hand the larger the diameter of the brake wheel the greater the torque exerted with a given pull on the magnet. The torque of a brake is equal to the force exerted by the brake shoes multiplied by the radius of the wheel. Its value is usually expressed in foot pounds, the diameter of the wheel being given in feet. The force exerted by the brake shoes is equal to the area of the shoe times the pressure per square inch permissible with a given lining. If we select a working pressure per square inch with a brake shoe lining that will give reasonable wear and have determined the maximum diameter of wheel that can be used we can then obtain the width of the shoe. It is found in practice that the percentage of brake wheel surface covered by the shoe remains constant and that the width of the brake shoe may be assumed to have a definite relation to the diameter of wheel. Assuming a definite ratio for these values and a fixed working pressure per square inch for the lining we obtain the curve shown in Fig. 246 which gives the relation between the torque and brake wheel diameter corresponding to these design limitations.

ADJUSTMENT FOR WEAR

As the brake lining wears down means should be provided for adjusting the shoes so that the clearance between the brake wheel and the shoes is kept within small limits, in order that the magnet may release them. This adjustment should be so arranged that if neglected the brake shoes will always set firmly against the wheel and the gap between the armature and core of the magnet be gradually increased. If this continues without attention in time the magnet will fail to release the brake. This condition will be apparent in the operation of the equipment and will therefore get attention. In no case should the design of the brake be such that the brake shoe will fail to set against the wheel.

MAGNET

Two types of magnets are available for brakes, the armature type and the plunger type. Theoretically the plunger type is the most efficient but the selection of the type of magnet depends upon the general design of the brake and its application.

Magnet coils can now be impregnated and treated to make them moisture resisting to a very high degree so that an open coil is satisfactory for most installations. Where this coil is exposed directly to the weather or for use on shipboard a totally enclosed magnet should be used.

The size of the magnet is determined by the pull required to release the brake shoes with the maximum air gap in the magnetic circuit. At this point most of the ampere turns are used to overcome the reluctance in the air gap so that the iron used for direct-current magnet frames can

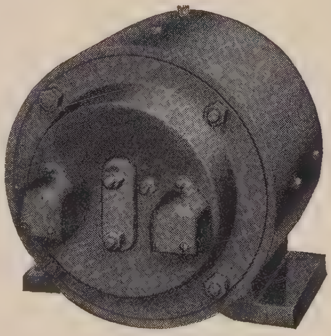

FIG. 244. Magnet Brake (Disc Type)

be selected on the basis of its cost rather than on its magnetic properties. Care should be taken in the design of the magnetic circuit to reduce the leakage paths to a minimum, and to prevent the iron core from becoming saturated, which reduces the pull.

A magnet should be large enough to release the brake shoes quickly. When series wound the brake coil is usually designed to release the magnet at 40 per cent of the rated load of the motor and hold the magnet in the closed position as low as ten per cent of the rated load of the motor. Series windings on direct-current magnets have several advantages, as follows:

(1) They can be connected in series with the motor armature, reducing complications in wiring.
(2) The coils have low inductance and therefore act quickly.
(3) Should the series motor overspeed it will reduce the current to a low value and allow the brake magnet to set, thus reducing the liability of a runaway.
(4) In case the armature circuit of the motor should be accidentally opened the brake will set. This is of particular advantage in lowering loads.
(5) The voltage between turns is so low that an insulation breakdown seldom occurs and insulating material can be used having high heat resisting qualities.

When a shunt winding is required for a direct-current brake it is advisable to design this winding for a relatively low voltage and use a resistance in series with it. In most cases a shunt resistance will also be required to take the discharge. The fewer the turns on a shunt coil the quicker it will act.

The alternating-current magnet presents some additional problems. The iron structure must be laminated to prevent eddy current loss and the pole face must be provided with shading coils to reduce the noise and eliminate vibration. The alternating-current flux passes through zero twice every cycle, therefore the magnetism will also pass through zero the same number of times. In order to prevent the magnet armature from releasing each time the current passes through zero, shading coils, consisting of a copper or brass strap, are placed around a portion of each pole face. These coils cause the magnetic flux in the area surrounded by the coil to lag behind the flux in the other part of the circuit so that there is always sufficient flux to hold the armature firmly against the pole face.

Alternating-current brake magnets of the smaller sizes are wound single phase but the larger sizes are sometimes wound polyphase. The current taken by the magnet with the armature gap open is considerable and it may be desirable to use a polyphase winding to distribute the load between the phases when larger size magnets are used.

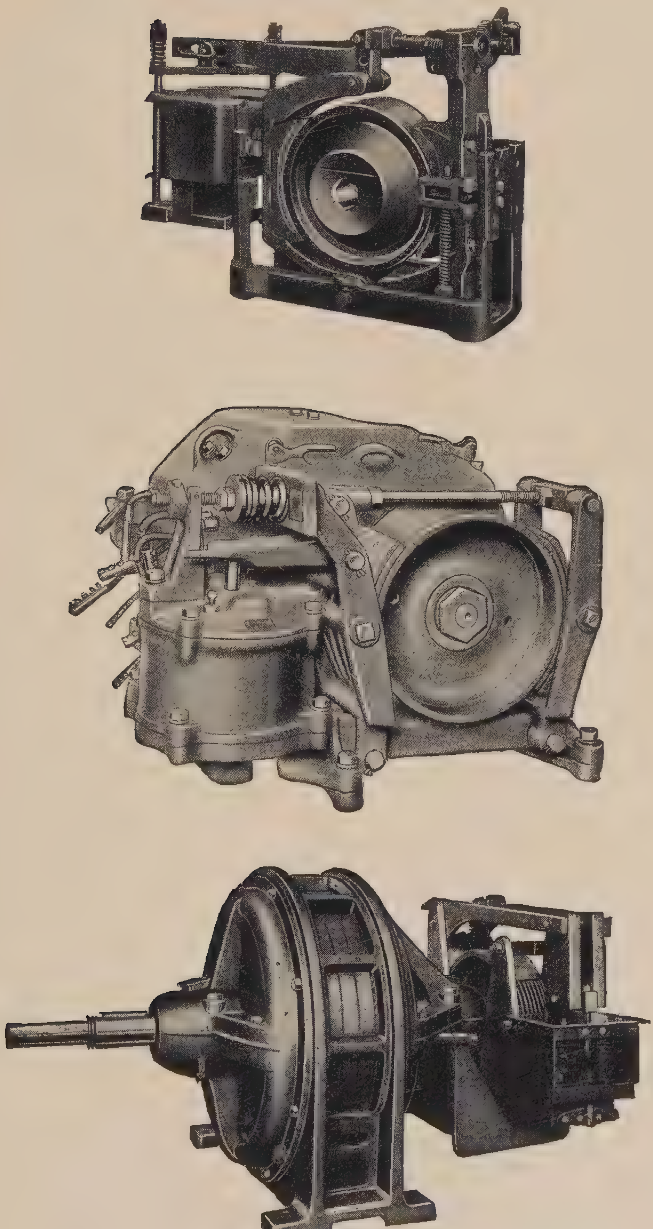

FIG. 245. Magnet Brakes

MECHANICAL PARTS

The brake structure supporting the magnet and shoes is very frequently made of cast steel in order to give it the proper strength. Stresses set up on portions of this structure are quite severe and are suddenly applied so that care must be taken in the design of the parts. When the brake magnet releases the armature a spring or weight forces the shoes against the brake wheel. The shoes travel only a very short distance, but some of the brake levers have more travel and store up considerable energy. This kinetic energy increases the pressure of the brake shoes against the wheel, and may cause the brake shoes to exert enough torque to twist off the motor shaft. In order to avoid this the brake lever attached to the magnet armature or core is usually arranged with a lost motion so that it can overtravel without exerting pressure against the brake shoes. Springs are preferable for applying the brake shoes as they have little inertia. Where a weight is used it should have a dashpot to control its action or some form of spring should be used to cushion the blow.

The size of the magnet is fixed by the pull required and the air gap through which the armature travels. In order to keep the design of these magnets down to a reasonable size, the brake shoes are given very little clearance when they are released. The magnet structure must therefore be very rigid so that there is little or no deflection in these parts; otherwise the magnet does work in deflecting these parts before it releases the shoes and the design is very inefficient.

DYNAMIC BRAKING

If a motor is driven by the load and its field remains excited, it will generate a voltage which if high enough will return energy to the line. The motor in this case becomes a generator and does work in holding the load. Such an arrangement is only useful where the motor is driven at a high speed. If it is desired to stop the motor this generator action can be used by connecting a resistor across the motor terminals, reducing it gradually, if necessary, to bring the motor to rest. This method of stopping a motor is known as dynamic braking. It is used very extensively for hoists and other moving loads that must be frequently stopped. The extra duty of generating the braking current increases the heating in the motor armature and must be taken into account in selecting the motor. This method does not use friction surfaces and there are therefore no parts to wear out. It is very useful in reducing the speed of the motor to a low value so that a friction brake is only required to stop the motor from the low speed and hold the load stationary.

In the chapter on cranes a system of dynamic braking is shown for use with series motors. The chapter on elevators shows the method of slow down and braking used for this application.

The use of dynamic braking is simplified by using only one step of resistance, but large installations may require contactors to short-circuit this resistance in several steps.

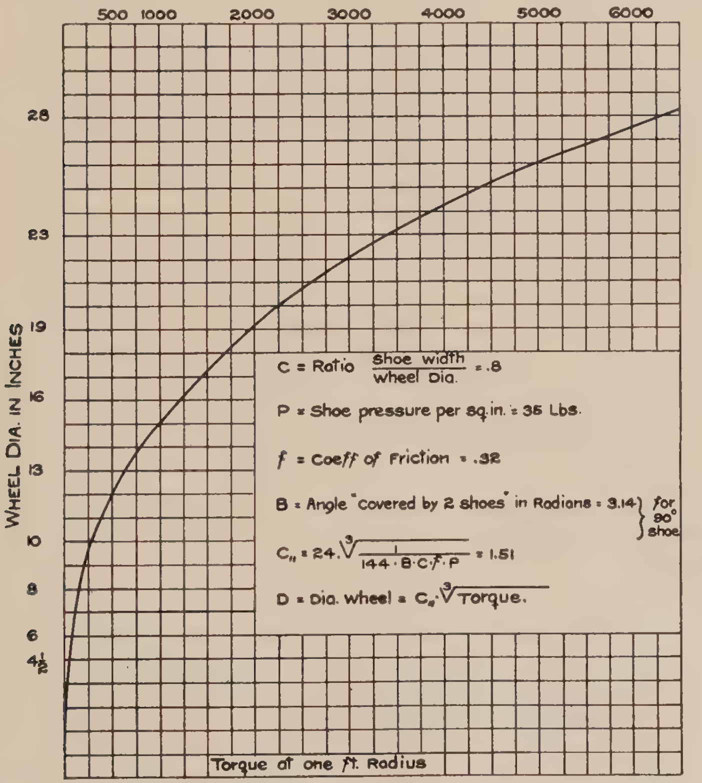

FIG. 246. Curve Showing Relation Between Torque and Wheel Diameter

An interesting application of dynamic braking is illustrated in Fig. 247, in connection with an adjustable-speed, direct-current motor. This motor has a four to one adjustable-speed range and very little energy is required to stop it from the low speed position. When operating at a higher speed the motor field is connected for its maximum value at the time the dynamic brake circuit is established. This causes the motor field to build up while the armature speed is being reduced. At first this increases the voltage of the motor terminals, causing an increased dynamic braking torque. As the speed is further reduced this voltage decreases rapidly. A relatively quick stop results without changing the value of the dynamic brake resistance.

Dynamic braking should be used whenever it is necessary to stop the motor quickly. It is more economical than a friction brake and requires less attention.

Applications

In applying a brake to a motor advantage can be taken of the friction in the machinery. In starting a load the motor must overcome both the load torque and the friction in the machinery. In stopping this load the friction of the machinery assists the brake. To illustrate let us assume a hoist having 80 per cent efficiency. If the torque required to accelerate the load is represented as 100 per cent, the torque required to stop the load in the same length of time would be represented as 64 per cent. In order to provide a reasonable factor of safety the friction brakes should be selected having a torque equal to the full-load torque of the motor. This assumption is based on the fact that many motors used on hoists and

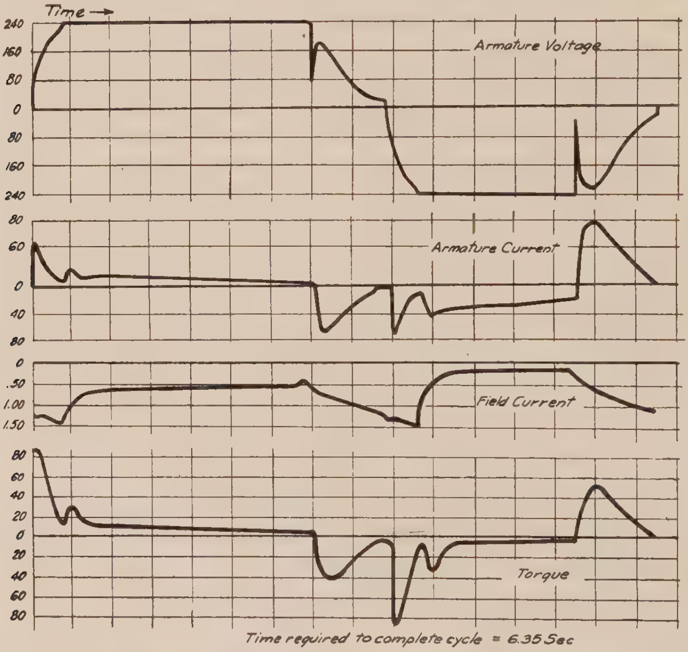

FIG. 247. Dynamic Braking with 4 to 1 Adjustable-speed D-C. Motor

similar applications exert more than their full-load torque during the accelerating period and therefore the brake should have full-load torque in order to provide a margin of safety.

If a brake is used to lower a load any considerable distance the energy required to maintain a fixed speed must be absorbed by the brake. This means that a great deal of energy will be absorbed by the brake and must be radiated from it. The size of the brake for such an application would be fixed not by the torque but by its ability to radiate energy. Steam hoists that use a lowering brake have a much larger brake than is common to motor applications. A comparison of this kind illustrates the advantages of using dynamic braking for lowering the load and a friction brake only for making the final stop and holding the load.

SUMMARY OF CHAPTER XXIII

A motor may be stopped by (1) friction braking, (2) dynamic braking.

Friction Braking: In the friction type of brake a removable cast-iron shoe to which is riveted a lining (usually of asbestos and rubber material interwoven with copper wire) is held against a (steel) brake wheel by a spring, and pulled away from it, or released, by a magnet. The coil of the magnet may be in series with the armature of a direct-current motor, but if for an alternating-current motor is shunt wound. For a-c. motors the brake coil may be connected across two of the motor leads so as to be energized simultaneously with the motor (or, polyphase coils are sometimes used, to distribute the current), but when reduced voltages are used at starting the brake coil is magnetized from a separate contactor.

Brake Wheel Diameter: To reduce its stored energy and fiber stresses in the rim the diameter of the brake wheel should be kept small. However, the larger the diameter the greater the torque exerted with a given pull on the magnet. The maximum diameter is limited by the distance between the motor shaft and floor level. The torque in foot pounds is equal to the radius times the area of the brake shoe times the maximum pressure per square inch permitted by the given brake lining. With wear the brake shoes should continue to set against the wheel and the magnet air gap increase.

Magnetic Circuit: The magnet must be large enough to release the brake quickly at the maximum air gap. Most of the ampere turns are consumed in overcoming the reluctance in the air gap. Hence for the frames of direct-current magnets the magnetic quality of the iron is of relatively minor importance, and a cheap iron may be used. Leakage paths should be kept small and the iron core should not become saturated or the pull is reduced.

Series Coils: Series-wound brake coils are usually designed to release at 40 per cent and hold in down to 10 per cent of the rated load of the motor. Series coils simplify the wiring, act quickly (having low inductance), and may prevent a series motor from running away if the current falls too low and the motor overspeeds. Hence, in lowering loads with a crane, if the armature circuit accidentally opens the brake sets. High heat resisting insulating may be used as the voltage between turns is low.

Shunt Coils: A resistance should be used in series with shunt coils so that the coil may be wound with a few turns, have a low inductance and act quickly. A resistance should be added in shunt with the coil to take care of the discharge.

Alternating-current Magnetic Circuit: The magnetic circuit of the a-c. magnet must be laminated and the pole face must have a shading coil to reduce noise and vibration. The shading coil maintains a constant flux by causing the flux in one part of the magnetic circuit to lag behind that in the other part so that when the voltage and unshaded flux pass through zero enough shaded flux is present to hold the brake magnet armature.

Overtravel of Brake Lever: To prevent too great pressure on the shoe, due to the momentum of the brake lever, provision is made for overtravel. The brake magnet structure, however, must be rigid to avoid loss of power due to lost motion.

Dynamic Braking: The motor, after being disconnected from the line, becomes a generator and its armature being driven by the load may be required, by maintaining the field excited, to force current through a resistor (dynamic braking), or if connected to the line and its speed is high enough, to return current to the line (regenerative braking). Dynamic braking is frequently used to slow the motor down and a friction brake to make the final stop. In stopping a motor by means of dynamic braking, usually the friction in the machinery is of assistance, making less than full-load torque necessary to stop the motor, if full-load torque is required for acceleration; but a brake capable of exerting full-load torque is generally used, to provide a margin of safety. When used in lowering loads brakes must be of large enough capacity to radiate the energy absorbed.

CHAPTER XXIV

REGENERATION

What regeneration is—two methods of regeneration—field control method—nine schemes of field control—voltage control method—by motor generator set—by booster—by combination of motor generator set and booster.

THE term "regeneration" is usually applied to a system of motor drive where the load exerts a negative torque and drives the motor as a generator, returning power to the system. It is similar to dynamic braking where the motor delivers power to a resistor, which transforms the energy into heat. A system using regeneration must have sufficient positive load to absorb all of the energy delivered, or a resistor should be arranged to absorb the surplus energy.

When regeneration is used for lowering a load, such as the cage of a hoist or a railroad train going down grade, the retarding torque will be lost if the circuit is open. It is necessary, therefore, to provide protective devices to hold the load by mechanical braking should the electric circuit become disconnected.

In order to obtain regeneration, the induced voltage of the motor or motors must be in excess of the voltage at which power is delivered, or, stated in another way, the motors driven as generators will deliver power to the line only if their voltage is in excess of the voltage at which the positive load is operating. Regeneration may be obtained from motors with shunt characteristics by operating them above their normal speed. For instance, an induction motor or a direct-current shunt motor when lowering a load will return power to the line and hold the load at a constant speed slightly in excess of the normal full speed of these motors. Reduced speeds can be obtained by increasing the field strength of a direct-current motor so that the required voltage will still be generated when the motor is operated below the maximum running speed. Several direct-current motors may be connected in series or parallel combinations, or, if an induction motor, the number of poles may be changed.

The regenerative system must provide for inherent current regulation so that the machines will quickly adapt themselves to any sudden drop in line voltage. This is usually taken care of by automatically changing the field strength of the motors. The line voltage may change too quickly to permit control apparatus to insert armature resistance to protect the motor.

Regeneration may be used to maintain the load at the maximum operating speed or it may be used to reduce the speed so that part of the energy stored in the moving load will be returned to the line. The stored energy is proportional to the square of the speed so that a reduction in speed to one-half of the maximum would mean absorbing three-fourths of the stored energy. If the speed is reduced to 20 per cent of the maximum before the final stop is made with friction brakes, only four per cent of the stored energy will be wasted.

There are many examples of regeneration with shunt direct-current motors or induction motors, such as hoists, elevators, etc. A notable example is that of freight locomotives using induction motors and regenerating when taking a train down grade. The inherent characteristic of these motors is such that regeneration is obtained with little or no additional complication.

Where it is desirable to make a material reduction in the speed by means of regeneration, additional features are necessary in designing the equipment. There are a number of different schemes for obtaining regeneration, but for purposes of simplicity they will be grouped under two main headings:

(1) field control;
(2) voltage control.

Field Control

In its simplest form this control consists of a direct-current shunt motor controlled by varying the strength of the shunt field, illustrated diagrammatically in Fig. 248. Commercial motors of this type can be obtained with a speed range of four to one. Such a motor can have its speed on regeneration varied in approximately this ratio. When operating at its maximum speed on a weak field, the field can be strengthened so that approximately 80 per cent of the stored energy of the load is returned to the line.

Modifications of this scheme are shown in Figs. 249 and 250. In Fig. 249 the field is excited from a storage battery, and is therefore independent of the line voltage. Fig. 250 shows the field energized from an exciter. The field of the exciter is connected to the line, and is therefore affected by variations in line voltage. If the exciter were self-excited it would be independent of the line voltage, provided it were maintained at a uniform speed. This exciter may be operated by a motor connected to the line with either shunt, series, or compound winding, or it may be driven by the main motor through suitable gearing. If located on a vehicle it may be driven by one of the axles. When schemes of control are shown involving an exciter it will be assumed that the exciter may be driven by any one of the above methods. Each arrangement has its advantages; the method used must be selected for the particular application. If all of the various schemes for regenerative control were shown, together with the various methods of driving the exciter, the subject matter would be complicated and difficult to follow.

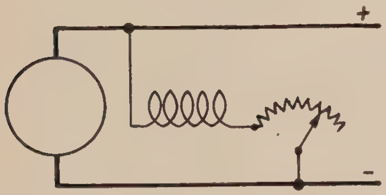

FIG. 248. Field Control Regeneration (Scheme 1)

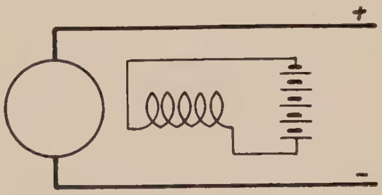

FIG. 249. Field Control Regeneration (Scheme 2)

The scheme shown in Fig. 248 is limited to a shunt motor. In the scheme in Fig. 249 or 250 the motor may be either shunt or series.

The three schemes just considered do not provide means for inherent regulation to protect the motor from overloads, caused by a sudden drop in line voltage. Fig. 251 is the same as Fig. 248, with the exception that the motor has a double winding, the series winding *B* opposing the shunt winding *A* and weakening the field strength on overloads. A drop in the line voltage will increase the motor current, and the strength of the compound winding, which opposes the shunt winding, will cause a reduction in the field strength, which in turn reduces the e.m.f. of the motor and maintains the current at a normal value. This regulating action, while inherently in the proper direction, will ordinarily be too slow, on account of the inductive effect of the shunt field winding.

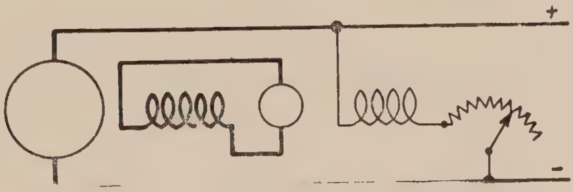

FIG. 250. Field Control Regeneration (Scheme 3)

The field *A* may be energized from a storage battery, Fig. 252, or from a separate exciter, Fig. 253. If energized from a storage battery, the windings may be either shunt or series. If series-wound, the inductive effect is relatively small and the regulating characteristics will change the field strength fast enough to prevent abnormal rises in current. The use of the battery makes the field strength independent of the line voltage. The arrangement of Fig. 253 is usually applied to a series motor

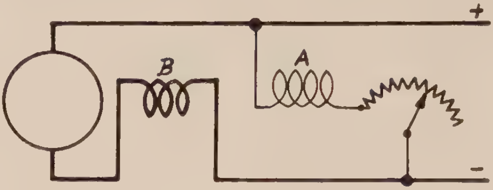

FIG. 251. Field Control Regeneration (Scheme 4)

and is dependent upon the line voltage, the fields of the exciter in this case being connected across the line. If these fields were self-excited a different set of characteristics would be obtained. Where the field strength is affected by the line voltage such as in Figs. 251 and 253, a

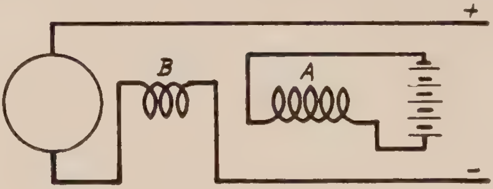

FIG. 252. Field Control Regeneration (Scheme 5)

drop in line voltage tends to reduce the field strength in itself, in addition to the action of the differential compound winding *B*. The arrangement in Fig. 252 depends entirely upon the differential winding *B* for its inherent regulation.

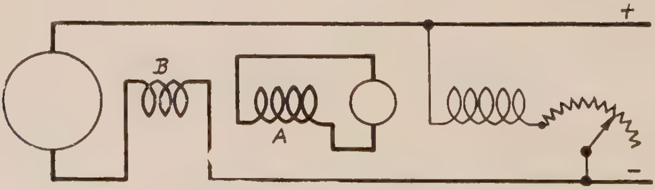

FIG. 253. Field Control Regeneration (Scheme 6)

It is desirable to make the main motor as simple as possible and not to interfere with its use in motoring. For this reason it is better to put the compound winding on the fields of the exciter rather than on the main motor. The arrangement shown in Fig. 254 is similar to Fig. 253, the difference being that the compound winding *B* which decreases the motor field strength on overloads is on the exciter field and not on the motor field.

Other arrangements for limiting the current when a decrease in line voltage takes place are shown in Figs. 255 and 256. The main motor field is connected in series with the exciter and in shunt with a small amount of resistance. The voltage on the field is equal to the voltage of the exciter minus the voltage drop caused by the current flowing through the series resistor. If the line current increases, the drop through this resistor also increases, and assuming that the exciter voltage remains constant the voltage on the field will decrease in proportion to the increase in line current. Fig. 255 shows an exciter with its field connected to the line. Fig. 256 has a battery substituted for the exciter. The arrangement in Fig. 255 is affected by changes in line voltage, whereas the excitation in Fig. 256 is independent of the line voltage. The arrangement shown in Fig. 255 has been used very successfully on large locomotives and responds very quickly to the changes in current caused by fluctuation in the line voltage. The use of a resistance in series with the motor armature also acts as a buffer although the value of this resistance is very low and the losses represent only about one per cent of the losses in the motor.

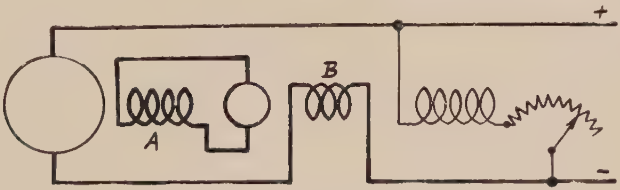

FIG. 254. **Field Control Regeneration (Scheme 7)**

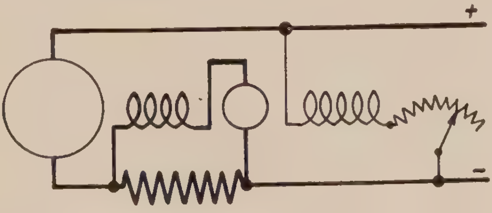

FIG. 255. **Field Control Regeneration (Scheme 8)**

The schemes which provide for automatic regulation of the armature current with fluctuations in line voltage, not only operate to hold the current down to a safe value when the line voltage decreases but they tend to maintain the line current close to the required value on an increase in line voltage. The increase in line voltage through the action of the compound winding or series resistance operates to increase the field strength and thus restore the current to its former value.

The speed of the motor on regeneration is adjusted by changing the field strength. Where a battery is used the number of cells in circuit can be changed. In other cases a rheostat is used in the field of the exciter. When the arrangement shown in Figs. 255 and 256 is used, adjustments can also be made by changing the ohms in the series resistor. Each particular application must be carefully worked out and a selection made of the scheme of control that is best adapted for that particular application. After the method of control has been determined the characteristics of the motor on regeneration can be adjusted by varying the amount of compounding where that form of control is used, or the series resistance in Figs. 255 or 256 may be changed. In addition to these two methods of adjustment the exciter is capable of a wide degree of adaptation by changing its driving means.

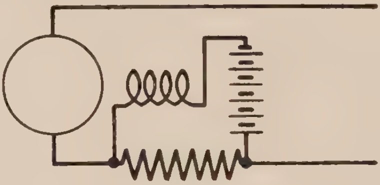

FIG. 256. Field Control Regeneration (Scheme 9)

VOLTAGE CONTROL

This method of control may be considered under three subheadings:
- (a) motor-generator set;
- (b) booster;
- (c) combination of motor-generator set and booster.

(A) MOTOR-GENERATOR SET

A direct-current shunt-wound generator (see Fig. 257) has its commutator connected directly to the commutator of a direct-current shunt-wound motor. Any standard type of motor may be used to drive the motor-generator set. The motor connected to the load has a constant field strength and a variable voltage impressed on its armature, by varying the field strength of the generator. To reverse the motor the generator fields are reversed.

The control scheme is a well-known method of obtaining regeneration, and is explained fully in Chapter XX. The speed range obtained on regeneration is practically the whole speed range of the motor in either direction of operation.

(B) Booster

A direct-current machine may be used as a "booster" (Fig. 258) or "bucker" in series with the main motor, which usually is a direct-current shunt-wound machine. When at rest the voltage of the booster is approximately that of the supply circuit. As the field strength of the booster is decreased its voltage goes down and the voltage on the motor increases until the motor is operating at line voltage. The fields of the booster may be reversed and gradually increase the voltage on the motor to approximately double the line voltage.

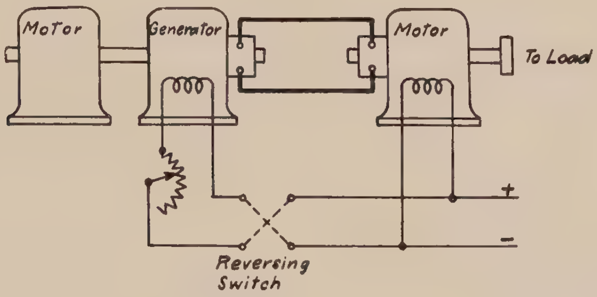

Fig. 257. Voltage Control Regeneration Using a Motor-generator Set

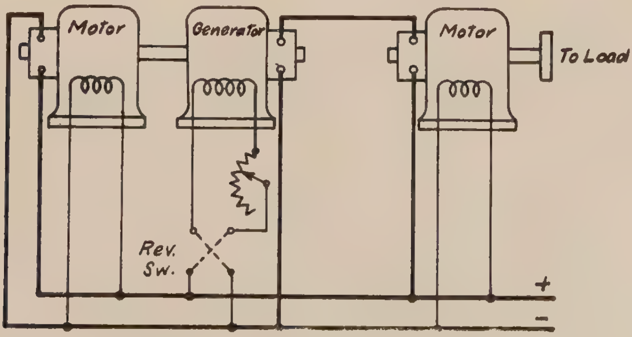

Fig. 258. Voltage Control Regeneration Using a "Booster"

Regeneration with this method may cover the entire speed range of the motor in both directions of operation. The booster may be driven by any form of motor, usually a direct-current shunt-wound machine.

(c) Motor-generator Set-booster

In this arrangement (Fig. 259) two direct-current shunt-wound machines are coupled together and connected in series across the supply lines. The working motor *C* is connected across the armature of machine *B* of this set; its field is shunt wound and has a constant value. The fields of the two direct-current machines forming the motor-generator set are varied inversely to each other. When the working motor *C* is at rest, the field of machine *A* is fully excited and machine *B* has its minimum field strength, which impresses a low voltage on the motor *C*. The field of machine *A* is gradually reduced and that of machine *B* increased until motor *C* is accelerated to full speed and the voltage of machine *A* becomes zero. When regenerating the voltage of machine *A* may be reversed so that it will assist machine *C* in delivering power to the line. The speed reduction during regeneration depends upon the voltage of machine *A*, and may extend over a wide range. Motor *C* may have its direction of operation reversed by reversing the connections to its armature.

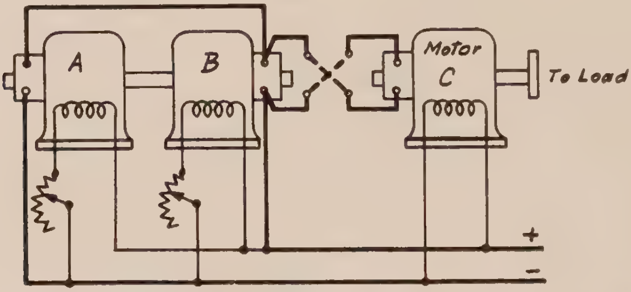

Fig. 259. Voltage Control Regeneration Using Combination Motor-generator Set and Booster

The scheme shown in Figs. 257 and 258 require the generator or booster to carry the full motor current all of the time, and deliver full voltage part of the time. These two limitations fix the size of this machine. The arrangement shown in Fig. 12 divides the motor current between machines *A* and *B*. When the motor *C* starts from rest its total current is supplied by both machines *A* and *B* in the inverse ratio of their voltages, the machine *B* supplying most of the current at slow speeds. This distribution of current permits smaller machines to be used than in the schemes shown in Figs. 257 and 258.

The last two arrangements show the motor and generator with shunt field windings only. These machines can be compound wound to obtain better operating characteristics from the motor driving the load. If this motor is operating a hoist its speed will change with a change in load due to the resistance in the armature circuit. This change in speed is known as regulation. The load may change from the maximum value in the positive direction to a negative load of perhaps fifty per cent of the maximum, so that a considerable change in speed may result. If series windings are used the motor can be given approximately a flat speed characteristic over the entire range of load.

When regenerating, a sudden drop in line voltage may cause an abnormal increase in the regenerating current. This condition can be taken care of in much the same way as described under field control. The service conditions will often determine the amount and frequency of voltage disturbances. In railway work a considerable drop in line voltage must be provided for, while in power work, particularly with the smaller hoists, elevators, etc., the voltage regulation is good. In many cases these motors are operated from the same lines that supply the lighting system. If an induction motor is used for the motor-generator set shown in Fig. 257, the ordinary changes in line voltage will be readily taken care of by the inherent characteristics of the motor. For large installations the induction motor is provided with a slip regulator which automatically adjusts the current fast enough to protect the motor from damage from voltage fluctuations.

General

The various forms of field control with the exception of that shown in Fig. 248 have their widest application in railway work. For the latter it is preferable to use series motors as they are freer from flashing troubles than shunt motors. These systems of control require the use of a rheostat for acceleration and speed regulation when motoring. The resistors are also required during regeneration when the motors are first connected to the line and also when the motor combinations are changed from parallel to series, etc.

The voltage methods of control have found their principal applications in the industrial field. The scheme illustrated in Fig. 257 is the one commonly used for large mining hoists and reversing steel mills. Voltage control does not require a resistor in the armature circuit of the motor. The only rheostats used are in the field circuits and consume very little energy. During acceleration and regeneration the ordinary rheostat losses are eliminated so that these systems operate very efficiently while the motor is connected to the line. During the time when the working motor is idle the operation of the motor-generator sets consume power and represent a direct loss. The control system can be arranged to shut down the motor-generator set during idle periods to avoid standby losses, if sufficient time can be allowed for starting the set before starting the working motor.

SUMMARY OF CHAPTER XXIV

Regenerated Voltage Exceeds Line Voltage: In regenerative braking the load drives the motor as a generator, returning power to the line. A mechanical brake is usually necessary to hold the load when the regenerative retarding effect is lost by accidental opening of the circuit. To return power to the line the regenerated voltage must be greater than the line voltage. This may occur at a speed slightly greater than normal, to which a motor may be held when lowering a load, for example, or the motor's speed may be reduced by increasing the field strength to obtain the necessary voltage at a lower speed. When in reducing speed energy is returned to the line, the energy lost is proportional to the square of the speed reduced to before stopping.

Protecting the Motor Against Overload: When regenerating, since the line voltage may change too quickly for control devices to insert resistance in the armature circuit to prevent the current from increasing and overloading the motor, the motor is usually protected by automatically changing the field.

Two Methods of Regeneration: Regeneration may be obtained by (1) field control, (2) voltage control. The simplest form of field control consists in varying the strength of the field of a shunt-wound direct-current motor. The field may be excited from the line or separately excited from a battery or exciter.

Field Control Method of Regeneration: The following are representative schemes of field control:

(1) Shunt-wound motor, field connected to line, rheostat in field circuit to vary strength of field. A maximum of 80 per cent of the stored energy of the load is returnable to the line.

(2) Shunt-wound motor, field excited from storage battery. The field strength is independent of the line voltage.

(3) Shunt-wound or series-wound motor, field energized from exciter (exciter may be self-excited or excited from line; may be driven by the main motor, or by a shunt-, series-, or compound-wound motor connected to line).

(4) Motor with shunt field, variable by rheostat, connected to line; and series field opposing the shunt field. When an overload occurs, caused by a sudden drop in line voltage, the series field current reduces the total field strength, reducing the e.m.f. of the motor and tending to lower the current to a normal value (the action is slow, however, due to the inductive effect of the shunt field).

(5) Motor with two fields, one (differential) in series with the line, the other (may be shunt or series) excited from a storage battery (if series, the inductive effect is small and the field strength changes fast enough to prevent abnormal rises in current). The field strength is independent of the line voltage: regulation is dependent upon the differential winding.

(6) Motor with two series fields, one (differential) in series with the line, the other energized from an exciter (exciter field, variable by rheostat, connected

to line; or, it may be self-excited). Regulation is afforded by the differential winding and reduction of the exciter field strength when the line voltage falls.

(7) Motor with one series winding, energized from exciter; exciter has shunt field, variable by rheostat, connected to line, and another field winding in series with line. Here the motor is not compounded but the compound winding is placed on the field of the exciter.

(8) Motor with one series winding, this in series with armature of exciter, resistor across series winding and exciter armature, exciter shunt field, variable by rheostat, connected to line. The voltage on the motor series field is equal to the exciter voltage minus the drop through the resistor (this drop increases as the line current increases, the voltage on the series field and consequently the field strength decreasing in proportion). The arrangement is affected by changes in line voltage.

(9) Motor with one series field, a storage battery between series field and line, resistor across field and battery. This arrangement is independent of the line voltage. If instead of decreasing, the line voltage increases the resistor drop and series field voltage increase and the series field is strengthened, tending to restore the current to its former value.

The speed during regeneration is adjusted by changing the field strength (by changing the number of battery cells in circuit, by a rheostat in the field of the exciter, or by changing the series resistance). The motor characteristics may be adjusted by varying the amount of compounding, or by varying the series resistance. The driving means of the exciter may also be changed.

Voltage Control Method of Regeneration: The voltage control method may employ:

(a) A motor-generator set: (armatures of the (shunt-wound) main motor and a shunt-wound generator are connected together, an auxiliary motor (any standard type) drives the generator). The motor field is constant, its speed being controlled by varying the armature voltage (by varying the generator field and in consequence the generator voltage).

(b) A booster: (shunt-wound main motor, a generator or booster with armature in series with line, auxiliary motor to drive generator). The field of the booster may be decreased, its voltage decreasing and the voltage on the main motor increasing until the latter reaches line voltage; the booster field may now be reversed and increased in the opposite direction until the motor voltage becomes double the line voltage.

(c) A combination of motor-generator set and booster: (shunt-wound main motor, auxiliary shunt-wound motor driving shunt-wound generator; all fields connected across line, the main motor's constant, the auxiliary motor's and generator's variable by rheostats; armatures of auxiliary motor and generator connected in series across the line, armature of main motor connected (through reversing switch) in parallel with armature of generator). Beginning with the main motor at rest, the generator field is at a minimum, the auxiliary motor field at a maximum. The two fields are varied inversely, the generator field being increased and the auxiliary motor field decreased, until the main motor is accelerated to full speed. Reduction of speed depends upon the voltage of the auxiliary motor which is reversed during regeneration to assist the main motor in returning power to the line. Smaller machines may be used than in schemes (a) or (b) since in the latter the generator or booster must carry the full current all of the time, in (c) it is divided between the auxiliary motor and generator. The machines may be compounded.

In railway work a considerable drop in line voltage must be provided for, while in industrial service (hoists, elevators, etc.) the voltage regulation is usually good. The various forms of field control are found mostly in railway work. Here series motors are preferred as being freer from flashing troubles than shunt motors, but series resistors and their consequent losses are necessary. Voltage control is mostly used in the industrial field. Series resistors are not required but standby losses occur if the motor is idle for long periods and the motor-generator set is kept in operation.

CHAPTER XXV

MACHINING TOOLS

Safety to operators—efficiency and production—motors—constant speed—adjustable and varying speed—controllers—manual type—magnetic type—tools—lathes—screw machines, automatic lathes, turret lathes—engine lathes—repair and jobbing, shaft and axle, speed, polishing, stud lathes—tool room lathe—banding lathe—winding lathe—milling machines—radial drill—boring mill—horizontal drilling, boring, and milling machine—planer.

THE machining tool field was one of the first to which individual electric drive was applied. Early promoters advocated its adoption because of the saving in power. This argument did not prove influential, as the cost of power in a machine shop represented only about five per cent of the total cost of operation, but after a few machine shops had been changed over to individual motor drive it was found that other advantages were obtained that far outweighed the saving in power, with the result that few today would be willing to return to the old system of belt drive from line shafting.

This chapter will deal with the general subject of electric drive for machine tools. The succeeding chapter will give details of some of the control equipment, illustrated by a few examples of particular applications.

In applying electric drive to machining tools, regard should be had (1) safety to the operator, (2) efficiency and production.

SAFETY TO OPERATORS

One of the most significant movements of the past few years has been the effort to guard employees from physical injury. The principal danger from electrical apparatus is that of a shock or burn, due to contact with live parts. Control apparatus should be so guarded that the operator will not come in contact with live parts when handling any of the control necessary for his work. It should also be protected so that tools, pieces of iron, chips, or other material cannot come into accidental contact with live parts. This may be accomplished by enclosing all current-carrying parts and providing projecting handles for the operation of the switches; or the control panel may be protected by grill work; or placed eight feet above the floor. The master controller should be arranged in a convenient manner so that the operator is not required to reach across his machine or in any way expose himself to injury during operation. This convenience will also increase production.

In some cases, it is desirable to provide several stations from which a machine can be stopped in case of accident. These stations usually consist of push buttons wired in series with the operating coil of the contactor or a low-voltage coil, so arranged that the pushing of any button opens the circuit and disconnects the motor from the line.

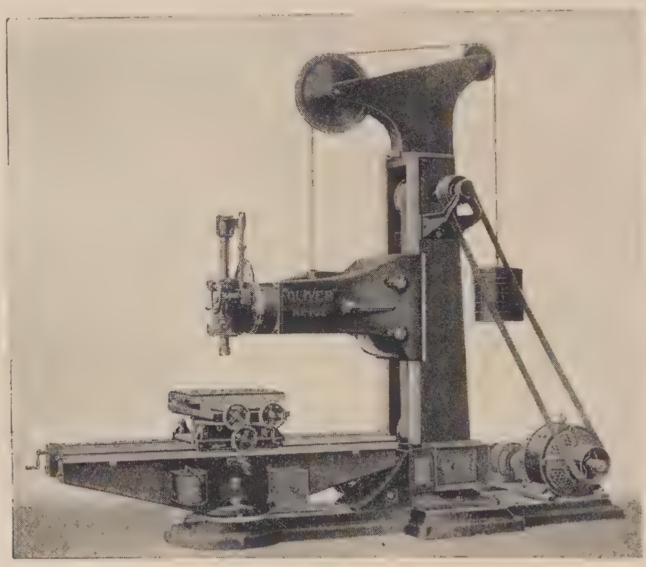

FIG. 260. Universal Wood Milling Machine

Driven by a reversible direct-current motor with speed adjustment by field control

The electric drive is well adapted to securing many desired safety features. Every machine tool control equipment should include the following:

(1) overload protection;
(2) low voltage protection;
(3) enclosure or protection of live parts;
(4) disconnecting means.

Overload protection limits the load that may be imposed upon the electric motor and the mechanical parts of the machine. Most controllers provide a relay that permits limited overloads to be carried for short periods of time.

Should the power circuit fail at any time, low voltage protection prevents the accidental starting of a machine tool on the restoration of voltage. This form of protection is very necessary, not only to prevent damage to the machinery, but also injury to the operator. The unexpected starting of any machine is a hazard and becomes of increasing importance with certain classes of machining tools.

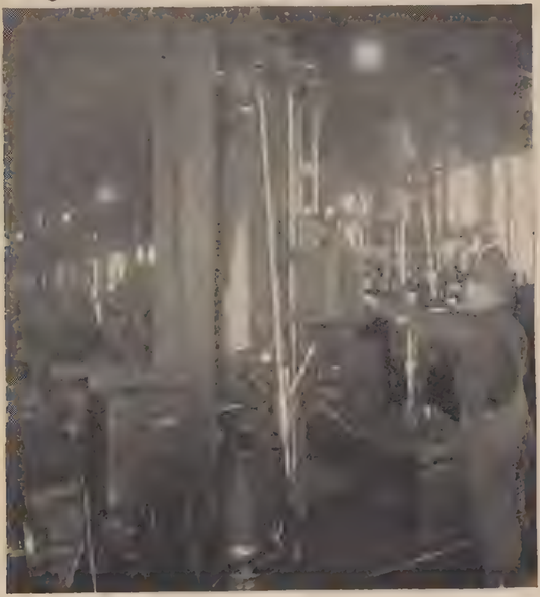

FIG. 261. Electrically-operated Radial Drill

Driven by non-reversing shunt motor with speed adjustment by field control

Obviously the enclosure or guarding of live parts is desirable and necessary. Operators and other persons engaged around machining tools should be protected against coming in contact with live parts or from being burned by arc or flash when circuits are opened.

A disconnecting means is necessary to permit inspection or repair of the electric equipment, or to render it safe for the operator to make adjustments and repairs to the machinery.

EFFICIENCY AND PRODUCTION

When properly selected and installed, electric drive has proved more efficient than belt drive. Among the advantages are the following:

(1) Standby losses in line shafting are eliminated when the tool is idle.
(2) Belt slippage is eliminated, resulting in a positive, even drive.
(3) The expense of belt renewal is avoided.
(4) By field control speed adjustment can readily be obtained without stopping the work.
(5) The direction of rotation can easily be reversed by means of a push button station or controller handle without the use of clutches.
(6) The acceleration of the motor may be made automatic when desirable.
(7) A dynamic brake can be provided for making a quick stop when power is shut off from the motor.
(8) A drift point can be provided on the controller for spotting work (this permits power to be shut off from the motor and the machine tool allowed to drift to the desired spot, when a quick, positive stop is obtained by applying the dynamic brake);
(9) The location of the tool is independent of a line shaft.
(10) Clear headroom and floor space may be procured, with good lighting and crane service.

In order to realize the greatest advantage from the electric drive a particular motor and controller must be selected for each machine tool; however, in providing control apparatus for machine tools, it is very desirable to have as many parts as possible interchangeable, so as to minimize the repair parts required, to make it easy for the electrician to understand the control apparatus and make replacements where necessary.

Motors

Motors driving machine tools may be considered under two classifications, (1) constant speed motors, (2) adjustable and varying speed motors.

Constant Speed Motors

Constant speed motors are frequently used for moving the tail stock of large lathes, cross rails, tool carriage of planers, boring mills, etc. These motors are usually of ten horsepower or less and are provided with reversing controllers. For machine tools requiring constant speeds only, the squirrel-cage induction motor has proved satisfactory. This motor has no external moving contacts such as a commutator or slip rings, and is rugged in construction. The shunt-wound direct-current motor is also used for constant speed service. The alternating-current and the small direct-current motors are connected directly to the line; the larger direct-current motors are provided with automatic acceleration.

A common form of controller for this application is shown in Fig. 262. The handle has a central or off position, with a position on either side of the center, when used with alternating current, to connect the motor to the line for forward and reverse operation. The same arrangement can be used for the smaller direct-current motors. Some are connected directly to the line and others have a fixed resistance in series to reduce the starting torque.

When used with the larger direct-current motors, two positions on either side of the central position of the handle are made available, since in this case it is often desirable to provide dynamic braking in the central position. When this is used, the first position on either side of the center is a drift position, which disconnects the motor from the line but does not apply the brake; the second position gives forward or reverse operation. This switch is adapted for connecting accelerating contactors in circuit for direct-current motors, where the size of the motor requires the use of automatic acceleration.

Some machine tools, such as lathes and drills, are provided with mechanical means for speed change and also mechanical means for reversing, and for these also constant speed motors may be used. This is particularly true of automatic lathes and screw machines. Another constant speed application is where the motor is belted either to a group of machine tools operating from one motor, or an individual machine. Applications of this type do not require any special features in the controller and the ordinary starters described in Chapters V and XIII can be used.

ADJUSTABLE AND VARYING SPEED MOTORS

The speed of a direct-current motor may be changed in two ways:

1. By changing the resistance in series with the armature. This is known as varying speed control. The speed of the motor on any notch of the controller depends upon the load on the motor, the light loads giving higher speeds than the heavy loads.
2. By changing the field strength of the motor, known as adjustable speed control. This gives practically a uniform speed for each notch of the controller.

Where adjustable speed is required the direct-current shunt-wound motor is always used. The speed of this motor is controlled by the strength of the field. Commercial motors are available for speed ranges of 3:1 and 4:1. Most of the standard motors will permit some change in speed and many permit as wide a variation as 2:1 by shunt field control.

Motors of this class, driving machine tools, comprise a wide range of applications. Considerable ingenuity is required to give the desired flexibility of control and at the same time avoid unnecessary complication.

Applications that do not require close speed regulation may use a compound-wound direct-current motor, or an alternating-current induction motor with wound secondary. Speed control is obtained in the direct-current motor with armature resistance, and in the alternating-current motor by resistance in the secondary. Motors of this type will have a variation of speed with each change in torque, and are known as variable speed motors.

Alternating-current motors are furnished for varying speed only. These motors are of the slip-ring type and have external resistance in the secondary circuit which is changed to vary the speed. The characteristics of control are practically the same as for a direct-current motor with armature control.

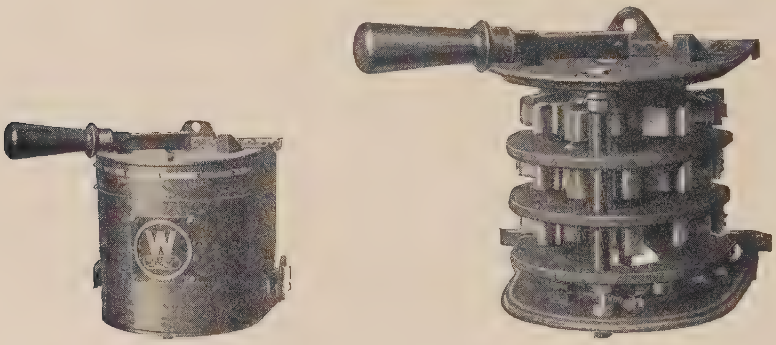

Fig. 262. Drum Reverse Switch for Direct-current Dynamic Braking Service

The use of a varying speed motor is uneconomical if the motor is operated much of the time at reduced speeds, as considerable loss occurs in the series resistance. A wide range of speed can, however, be obtained with a less expensive motor than if adjustable speed were used, and for some applications having intermittent service, such as bending rolls, this form of motor is satisfactory. The adjustable speed direct-current motor is the one usually employed where a change in motor speed is required.

Controllers

The controller may consist only of a starting device providing overload and low voltage protection, or it may be more complicated, depending upon the several operations necessary to be performed by the motor. Among the principal functions of the controller are the following:

(1) to start and stop the motor;
(2) to reverse the direction of rotation;
(3) to change the speed of the motor;
(4) to provide a dynamic brake for stopping;
(5) to provide a drift point when required;
(6) to provide overload protection;
(7) to provide low voltage protection.

Table VIII shows various controller combinations that may be recommended for use with direct-current and alternating-current motors for some of the principal machining tool applications. Other combinations are in successful use and special combinations can be made when necessary, but experience has shown that the combinations given in the table are those in most common use and in general give the best satisfaction.

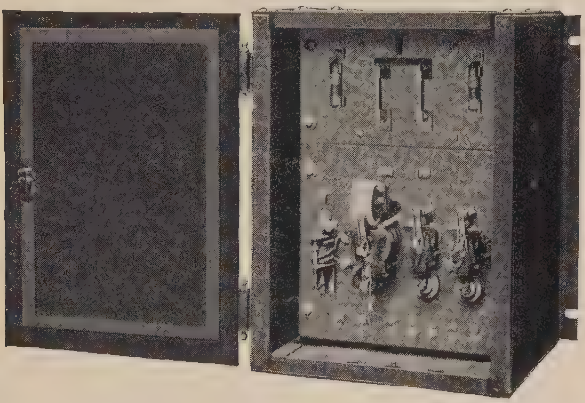

Fig. 263. Controller with Overload
(Magnetic Contactor Controller Embodying One Type of Overload Relay)

Manual Controllers

Controllers may be manually operated, magnetically operated, or a combination of manual and magnetic control may be used. Manual controllers may be of the drum type or face plate type. When the speed is controlled by changing the strength of the motor field, the rheostat is usually of the face plate type and operated manually, but an exception to this is the drum controller with a field rheostat made up in the drum form.

TABLE VIII

MAGNETIC CONTROL FOR MACHINE TOOLS

This table covers a typical list of magnetic control for adjustable speed direct-current motors, suitable for general application in the average large machine shop. Braking, drift, and arrangement of field rheostat in different combinations form the basis of most machine tool controllers.

Tool	Form	Range in Size	Hp. Range	Speed Ratio	Controller	Rev.	Dynamic Brake	Drift Point	Master Switch	Field Rheostat
Lathe	Automatic	4½ to 8 inches	3 to 15	2 : 1	Magnetic	No	No	No	Push button	Separate
	Cut off		5 to 20	2 : 1	Magnetic	No	No	No	Drum type	With master
	Engine	16 to 60 inches	3½ to 20	3 : 1 4 : 1	Magnetic	Yes	Yes	Yes	Drum type	With master
	Vert. turret	24 to 42 inches	3½ to 15	2 : 1	Magnetic	No	No	No	Push button	Separate
	Horiz. turret	18 to 36 inches	3½ to 15	4 : 1	Magnetic	No	Yes	Yes	Drum type	With master
	Screw cutting		5 to 15	3 : 1	Magnetic	Yes	Yes	Yes	Drum type	Separate
	Car wheel	42 to 90 inches	20 to 50	2 : 1 3 : 1	Magnetic	Emer.	Yes	No	Push button	On panel
Boring mill	Vertical	30 to 192 inches	5 to 30	3 : 1	Magnetic	No	Yes	No	Push button	Separate
	Horizontal	2 to 4 spindle	7½ to 10	4 : 1	Magnetic	No	Yes	Yes	Drum type	With master
* Boring mill †	For segmental turning				Rev. planer	Yes	Yes	No	Planer	On panel
Milling machine	Horizontal	18 × 8 × 19 in. to 42 × 14 × 20 in.	3½ to 15	4 : 1	Magnetic	No	No	No	Drum type	With master
	Slab		15 to 75	3 : 1	Magnetic	No	No	No	Drum type	With master
Drills	Gang	4 to 6 spindle	5 to 15	4 : 1	Magnetic	No	No	No	Drum type	With master
	Radial	4 to 10 feet	4 to 20	3 : 1	Magnetic	No	No	No	Drum type	With master
	Upright	20 to 30 inches	2 to 7½	2 : 1	Magnetic	No	No	No	Drum type	With master
	Portable	8 to 18 inches	1½ to 10	4 : 1	Magnetic	No	No	No	Drum type	With master
Planer †	Reversing		10 to 75	4 : 1	Rev. Planer	Yes	Yes	No	Planer	On panel
	Non-reversing		7½ to 30	2 : 1	Non-reversing planer	No	No	No	Planer	On panel
Shaper	Horizontal	16 to 36 inches	3 to 10	3 : 1	Magnetic	No	‡	No	Push button	Separate
	Vertical	6 to 12 inches	1 to 7½	3 : 1	Magnetic	No	‡	No	Push button	Separate
	Draw cut		Special		Rev. planer	Yes	Yes	No	Planer	On panel
Saw	Band	48 inches	1. to 7½	2 : 1	Magnetic					
	Gold toothed		2 to 25	2 : 1	Magnetic					
	Gold plate		Up to 200	2 : 1	Magnetic					

* If the shape of the work is such that a number of pieces cannot be put on the table, so the tool cuts at least 40 per cent of the time, a considerable increase in production can be obtained by using a reversing planer equipment.

† Dynamic braking desirable where work is changed frequently.

‡ Cut and return speed.

Manual controllers should be entirely enclosed. The resistor may be mounted as a unit with the controller, but while satisfactory for the smaller size of controllers the combined mounting becomes unwieldy for large motors. The manual controller does not incorporate within itself all of the necessary protective features and a separate protective panel is therefore required. The acceleration of motors with manual controllers is entirely at the will of the operator, automatic features not being incorporated with this type.

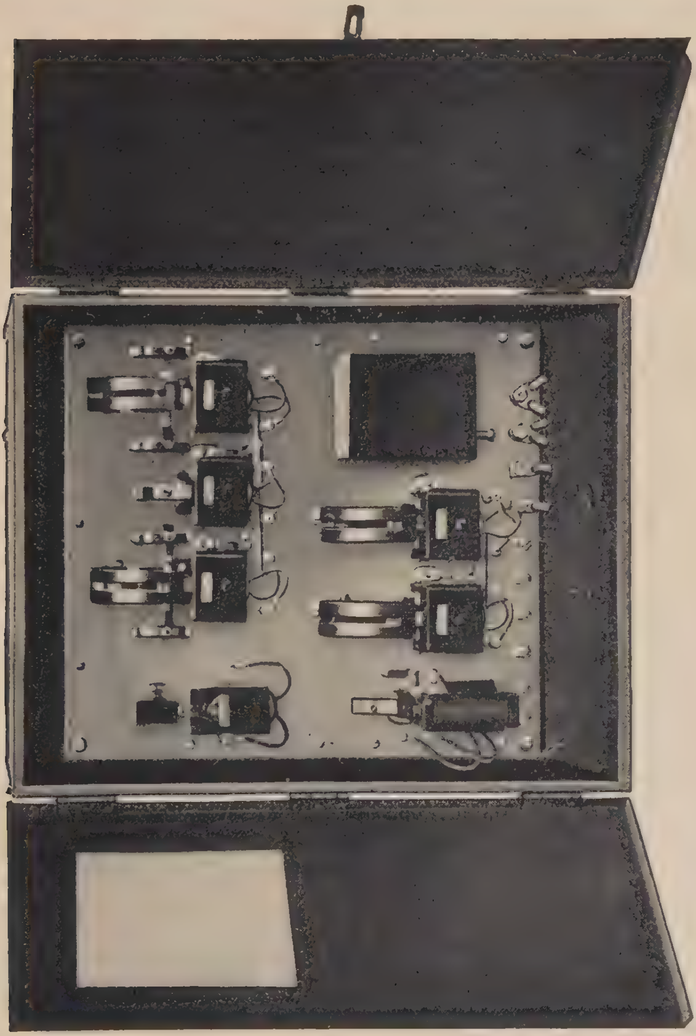

FIG. 264. Automatic Starters, 50 HP., 230 Volts

Manual controllers, particularly the smaller sizes, are well adapted for mounting directly on the machine, of which the lathe is a good example. The controller may be connected to the spline shaft of an engine lathe so that the motor can be started, stopped, reversed, and its speed changed, at the tool carriage. In some cases, the starting, stopping, and reversing only of the motor are performed by a manual controller, usually of the drum type, the acceleration of the motor and the protective features being incorporated in a separate panel. The field control may be separate or a part of the manual controller.

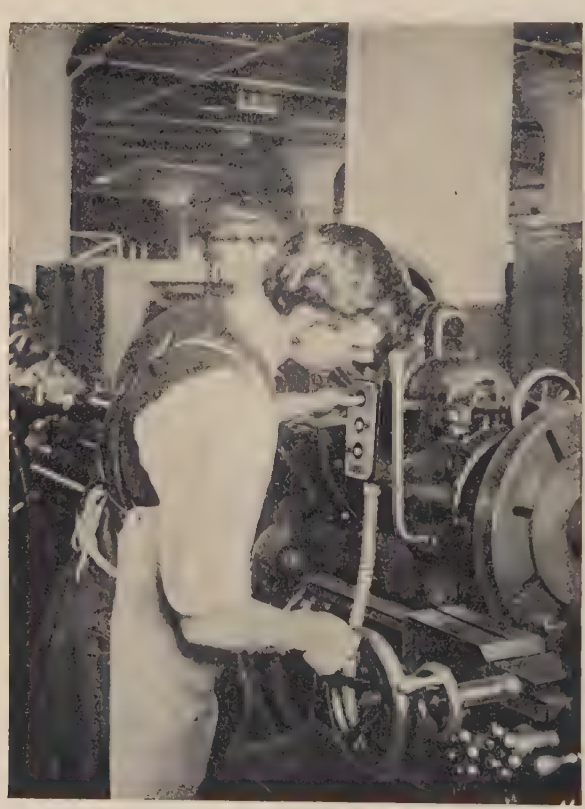

Fig. 265. Push Button Mounted on Lathe

Magnetic Controllers

Magnetic controllers consist of a cabinet in which are mounted the necessary panel, magnetic contactors for starting and stopping the motor, and protective features. These controllers may have contactors also for reversing the direction of the motor. Speed control is usually obtained by means of a separately mounted field rheostat. A master controller is required, either of the push button type, or combined with the field rheostat in the face plate or drum construction.

Many machine tools are so compact as not to afford a ready location for attaching a drum type controller. These may be conveniently operated from one or more push button stations. When it is desired to control the machine from more than one location, additional push button stations are provided. A machine tool may, prior to operation, be set for a given speed by means of a manually operated field rheostat. The tool is then started and stopped at will by a push button, the motor in each case accelerating to a speed corresponding to the setting of the rheostat. The latter is often provided with an indicating plate marked to show the cutting or spindle speed for each setting.

Classification of Tools

In the following paragraphs it is attempted to classify and describe briefly some of the more important machining tool applications.

Lathes

The primary function of a lathe is to machine, externally or internally, a cylindrical surface of one or more diameters, and to face the ends of the piece being machined. Additional operations, such as screw cutting, taper turning, etc., may be performed, and attachments for many various functions are furnished by tool builders. The control selected for a lathe depends upon the operations to be performed, but to enumerate all the types of lathes is practically impossible, owing to the great variety built for specific operations. General purpose lathes may be grouped into comparatively few classes, as indicated in Table VIII, in which their principal functions and the types of control applicable to them are given.

Screw Machines, Automatic Lathes, Turret Lathes

These three types have many functions in common and will be grouped. The type of motor and controller for each is the same. These lathes are equipped with a turret head and some have multiple spindles. The turret head consists of several tool holders around a central axis, each performing one operation. The operation is automatic, the tools being brought successively into action so as to complete all operations included in the range of the setup on the machine. On multiple spindle machines, each tool is working simultaneously on a different piece.

These machines may be driven by a constant speed motor, the proper speed for each setup being adjusted by mechanical means, or an adjustable speed motor may be used, controlled by a field rheostat. The rheostat may be present for a particlar speed at the time the setup of the tool is made, or a cam or other mechanical means may operate the rheostat during or between operations to vary the speed of the motor. With the automatic lathe a constant speed motor is generally used, with the other two types either the constant or adjustable speed.

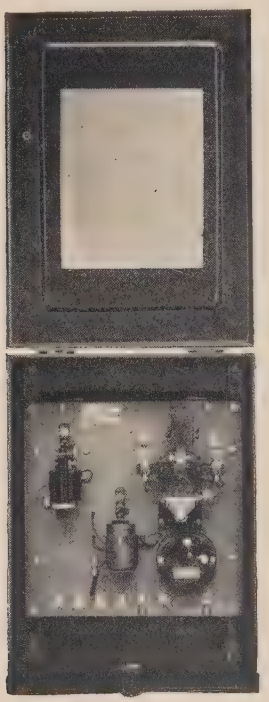

FIG. 266

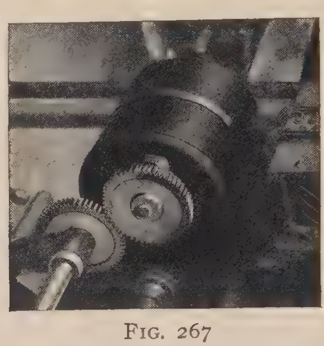

FIG. 267

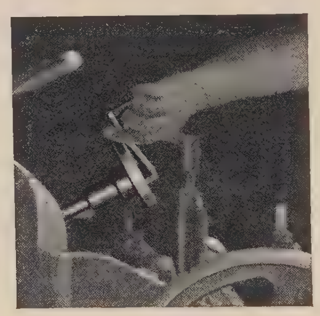

FIG. 268

FIG. 266. Machine Tool Panel 15-25 HP. 230 Volt, Adjustable Speed Reversing Panel in Enclosing Case Floor Mounting

FIG. 267. Drum Controller with Geared Spline Shaft Drive on Lathe

FIG. 268. Spline Shaft Control

When the speed is controlled by adjusting the field strength of the motor, it remains practically constant for each setting of the rheostat. The losses are small.

ENGINE LATHE

This type has a single spindle but may have more than one tool carriage. Adjustable speed is usually required and for this reason direct-current motors are used. It may have an attachment for tapering, or one for screw cutting. If for the latter, a reversible motor is required. Other lathes may or may not have reversible motors.

For small lathes the controller is usually of the drum type. Where the motors are large, better results are obtained by using a drum type master switch combined with a field rheostat, with a separate control panel for automatic acceleration of the motor. The panel may provide the reversing feature, or the reversing switch may be combined with the master switch.

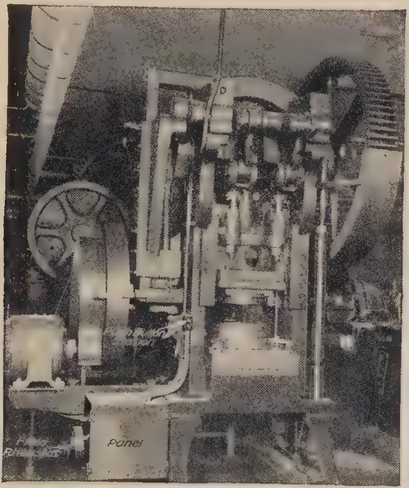

FIG. 269. Adjustable Speed, Non-reversing Equipment on a Toggle Press Driven by a 10-HP. Motor

REPAIRING AND JOBBING, SHAFT AND AXLE, SPEED, POLISHING, STUD LATHES

All of these lathes are modifications of the engine lathe, adapted to their special purposes. Some parts of the engine lathe are omitted, other parts simplified. Additional features are sometimes added to facilitate the particular work for which they are to be used. The control is substantially the same as that for the engine lathe with adjustable speed motors.

TOOL ROOM LATHE

This is a modification of the engine lathe with additional features such as grinding, screw cutting, and taper attachments. It is intended for accurate work and is capable of fine adjustment. An adjustable or constant speed, reversing or non-reversing motor may be used.

Banding Lathe

This is not a machine for cutting metal. Its purpose is to wind banding wire around the outside of armatures for electric machines and other apparatus of similar construction. It comprises a head and tail stop, mounted on a bed, with a tension device for holding the wire taut.

An adjustable speed shunt-wound motor and a non-reversing controller are used, except when direct current is not available and an alternating-current motor is used, when changes in speed are obtained by the gear box or similar device.

Winding Lathe

This lathe is in the same class as the banding lathe. It is not used for cutting but is designed for winding wire on mandrels and forms of various types. Its design depends largely upon the work to be done. It is intended for winding coils for electric machines, and cooling coils for transformers, but in addition to winding it may be arranged for forming the coil to a given shape.

These lathes may be operated by either constant speed or adjustable speed motors. Most of these machines are designed with a particular purpose in view and various automatic features may be added which will modify the electrical equipment.

Milling Machines

The milling machine is designed to remove metal by means of a rotating cutter. The machining may be across a flat horizontal or vertical surface, or in a groove or keyway. Frequently several cutters are used to finish different surfaces on one piece at the same operation. Milling cutters ordinarily bear teeth on the outer edge of the disc or cylinder, but some are arranged with the teeth in the end of a cylinder, known as end millers. The cutter is mounted on a rotating stationary arbor, the work being moved relatively to the cutter by a table or platen.

A large proportion of milling machines are driven by a-c. or d-c. constant-speed motors. Changes in spindle speed are obtained by mechanical means. Milling machines are non-reversing, except slab millers, which may be reversing or non-reversing. When an adjustable-speed direct-current motor is used, either part or all of the speed changes are obtained by adjusting the field strength of the motor.

RADIAL DRILLS

These machines are primarily for the purpose of drilling holes, by means of a rotating spindle. The work is usually held stationary on the drilling table or bed plate, the spindle being mounted in a head which may be raised or lowered or moved in and out to accommodate the work. The holes may also be tapped or reamed. The drill may be fed into the work by hand, or automatically by suitable gearing. The spindle speed and the rate of feed are adjustable for different materials and hole sizes.

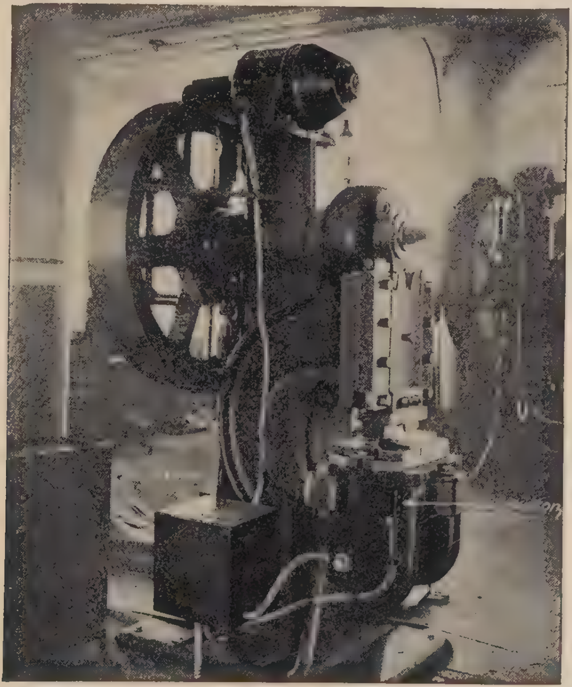

FIG. 270. Constant Speed, Non-reversing Equipment on a Punch Press Driven by a 5-HP. Motor

Combination drilling tools may be used for counterboring a hole and for facing a spot around the hole. A clutch may be provided to stop the drill without stopping the machine. Reversing the drill may be arranged for, useful in tapping holes.

Multiple spindle drills are common. They consist of a number of separate spindles that can be moved relative to each other, so that individual drills may be properly centered. By properly setting the drills a number of different holes may be bored in a single piece in one operation. If the drills vary in diameter the maximum drilling speed is fixed by the diameter of the largest. This drill is useful for quantity production, such as in the manufacture of parts of automobiles.

Constant speed motors are universally used. Reversing may be provided but is usually taken care of by mechanical means. Tapping machines that stop the tool automatically at the bottom of the hole are sometimes provided with reversible motors and automatic controllers.

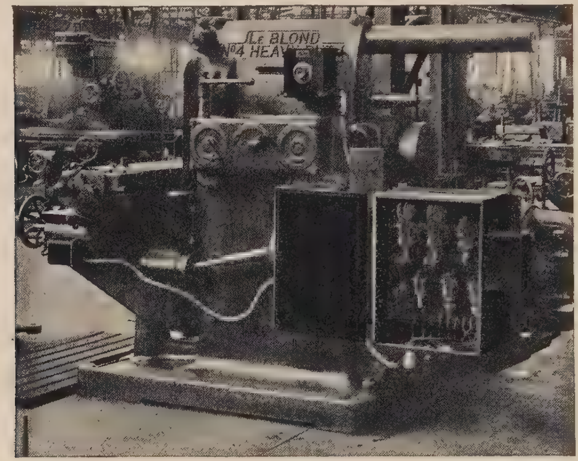

FIG. 271. Non-reverse Controller on a Milling Machine Drive

BORING MILLS

Boring mills machine the outside or inside surface of a cylinder or circular piece and also across the face of the piece. They resemble both the engine lathe and the drill. The work is mounted upon a horizontal rotating table, the tool is held stationary in a head which can be raised, lowered, and moved horizontally. Tool feed is automatic, adjusted by changing the gearing. The speed at which the table rotates is adjusted by gear changing or the speed of the driving motor may be altered.

Usually a direct-current adjustable-speed motor and non-reversing controller are used. A special application uses a reversing motor and gives the table an oscillating motion. When only a small section of the total circumference of the work is machined, this method is quicker than to revolve the work continuously. The method of control is similar to the reversing planer equipment (described under planers).

HORIZONTAL DRILLING, BORING AND MILLING MACHINE

The tool of this machine moves in a straight line with a reciprocating motion, as in planers. A slotter and key seater have the tool moving in a vertical direction, a shaper in the horizontal direction. The work is held stationary on a table. The machine tool itself may be relatively small, as the amount of metal removed is not great. It is particularly useful in cutting keyways and in machining into corners and around edges. Box-like structures, such as brush holders, may thus be machined.

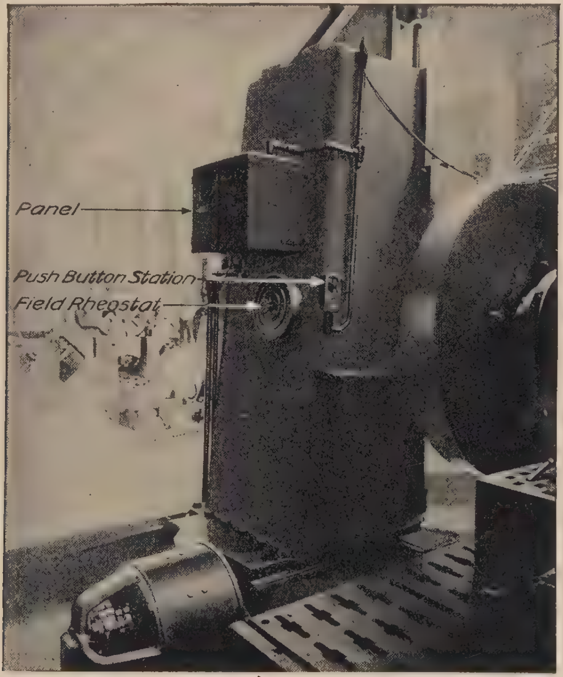

FIG. 272. Adjustable Speed, Reversing Equipment on a 12-in. Horizontal Boring Machine Driven by a 20-HP. 2:1 Motor

The motors are constant speed, either direct or alternating current, the controllers non-reversing. The tool is reversed and the speed changed by mechanical means.

PLANERS

The tool carriage of the planer moves in a straight horizontal line with a reciprocating motion. The machining may be across a flat horizontal or vertical surface, or grooves or slots may be cut. The material to be machined is usually mounted on a large bed or platen which moves horizontally under two or more tool heads held by a crossarm supported on a vertical frame. The cut is adjusted or changed by moving the tool horizontally along the cross head in a direction at right angles to the motion of the platen. The cross head may also be moved vertically up or down and two motions imparted to the tool.

The main drive for the planer accomplishes the movement of the platen back and forth, usually by means of a direct-current motor geared directly to the platen. Speed adjustment by field control is provided. Two rheostats are used, one controlling the cut stroke, the other the reverse stroke. The reverse motion is usually at a higher speed than the cutting motion.

Smaller motors raise and lower the cross head, also move the cross carriage of the tool travel. These motors are usually thrown directly on the line in the proper direction of motion; in some cases they are automatically controlled to give the necessary feed motion to the tools.

Special planers have been made for special applications. An important modification is the plate planer, designed for machining the edge of long plates. These provide a cutting motion in both directions of travel.

SUMMARY OF CHAPTER XXV

Safety: The electric drive for machining tools should be made safe for the operator. Apparatus should be guarded to prevent touching live parts, emergency stop push button stations may be located at points where needed, and overload and low voltage protection, and a means of disconnecting the electrical apparatus from the line when inspecting or repairing, should be provided.

Advantages of Electric Drive Over Belt Drive: The main advantages of individual electric drive for machining tools, over belt drive from a line shaft, are:

(1) line shaft standby losses are eliminated;
(2) the drive is positive, belt slippage being eliminated;
(3) the expense of belt renewal is avoided;
(4) the speed is adjustable without stopping the work;
(5) the direction or rotation is easily reversed;
(6) quick stopping by dynamic braking may be obtained;
(7) drift is easily provided;
(8) the location of the tool is independent of line shafting;
(9) the saving of space enables better lighting, crane service, and working space to be provided.

A motor and controller should be specially selected for each tool, but it is also an advantage to have parts as standard and interchangeable as possible to facilitate repair.

Motors for Machining Tools: For some machining tools constant speed motors and controllers may be used, others require adjustable or varying speed motors and control. In adjustable speed control the motor speed is changed, independently of load, by adjusting the motor field strength. Resistance losses are less with this method, if the motor is operated for considerable periods at reduced speeds. In varying speed control, resistance in series with the armature (of a d-c. motor, or in the secondary circuit of an a-c. motor) is changed. The speed varies also inversely as the load. This method may be used when the motor is operated intermittently at reduced speeds.

CONTROLLERS: The principal functions of machining tool controllers are:
(1) to start and stop the motor;
(2) to reverse the direction of rotation;
(3) to change the speed of the motor;
(4) to provide a dynamic brake for stopping;
(5) to provide a drift point;
(6) to provide overload protection;
(7) to provide low voltage protection.

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Book No. 356.

Manual controllers should be enclosed and such necessary protective features as are not provided should be included in a separate protective panel. Resistors and a field rheostat in the drum form are sometimes included in drum type controllers.

Magnetic controllers usually comprise a cabinet mounted contactor panel and a master switch which may be a push button station, or may be of the face plate or drum type, combined with a field rheostat (or the latter may be separate).

MACHINING TOOLS: A lathe machines externally or internally a cylindrical surface of one or more diameters and faces the ends of the piece being machined. In addition, turret lathes, automatic lathes, and screw machines have a turret head, consisting of several tool holders around a central axis, each performing one operation upon the piece; and sometimes multiple spindles, each containing one tool and all working simultaneously.

An engine lathe has one spindle but may have more than one tool carriage, also a tapering or a screw cutting attachment. Repair and jobbing, shaft and axle, speed, polishing, and stud lathes are engine lathes modified to suit a particular purpose. The tool room lathe is an engine lathe modified by adding grinding, screw cutting, or tapering attachments.

A banding lathe winds banding wire around motor armatures, etc. Similar to it is the winding lathe which winds, or winds and forms into shape, coils for electrical apparatus.

In a milling machine a rotating cutter removes metal from horizontal flat surfaces, grooves, keyways, etc.

In the radial drill an arm, movable radially, and holding the drill spindle, may be raised, lowered, or moved in or out to accommodate the work, which is held stationary: multiple spindles may enable several holes to be drilled simultaneously (much used in making automobile parts). A boring mill machines the inside or outside surface of a cylindrical or circular piece and across its face. The horizontal drilling, boring, and milling machine operates in a straight line with a reciprocating motion in a vertical (slotter, key seater) or horizontal direction (shaper).

Planers usually have motors giving three motions, one (up and down) of the cross head holding the tool, a second (back and forth across the work) of the tool cross carriage, and the third, the main or lengthwise movement of the bed or plates holding the work. Usually the reverse movement or return stroke of the platen is faster than the forward or cutting stroke. A plate planer cuts in both directions of travel.

CHAPTER XXVI

MACHINING TOOL APPLICATIONS

Machining tool controllers—twelve combinations—applications—wood milling machine—radial drill—turret lathe—wheel lathe—reversing planer—non-reversing planer.

If the control of machine tools be analyzed, the various arrangements may be classified as follows:

1. *Non-reversing Control Panel.*—The wiring diagram of this panel is shown in Fig. 274. It consists of a line contactor and one or more accelerating contactors, together with the starting resistor. The panel should also contain a knife switch and overload protection by either fuses or an overload relay. It is preferable to mount this panel in a cabinet and arrange the handle of the knife switch so that the switch can be opened from the outside of the cabinet and can be locked in the open position to prevent the accidental starting of the machine tool when the attendant is adjusting or repairing it. This knife switch should be used only for disconnecting, and the motor should be started and stopped with the line contactor. The connections provide for low voltage protection. One of these controllers is shown mounted in a cabinet in Fig. 274.

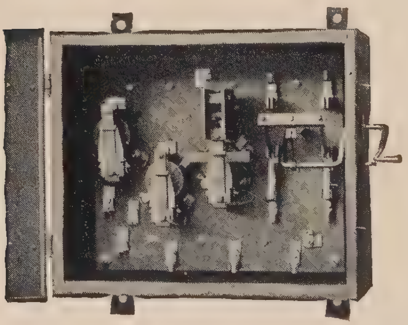


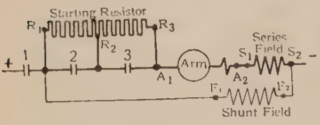
Fig. 273. Non-reversing Controller. Mounted in Cabinet

2. *Non-reversing Control Panel with Dynamic Brake.*—The diagram of connections for this control panel is shown in Fig. 275. It is the same as for the control panel shown in Figs. 273 and 274, with the addition of a back contact, to provide for dynamic braking. The diagram also shows the connections to a field rheostat.

3. *Non-reversing Control Panel with Dynamic Brake and Drift.*—Fig. 276 is the same as Fig. 275, with the addition of a second line contactor to provide for a drift point in addition to the dynamic braking. By opening this extra line contactor, the motor is disconnected from the line on

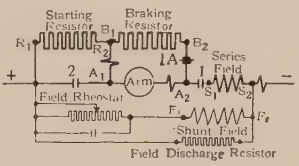
this side and allowed to drift. When the other line contactor is opened, it disconnects the opposite side of the motor from the line and the back contact closes, giving dynamic braking.

4. Reversing Control Panel.—This panel, Fig. 277, has four line contactors and one or more accelerating contactors, together with the necessary resistor. It should also have a knife switch and overload protection and should be mounted in a cabinet, as described for the controller under item *1*, Figs. 273 and 274.



Con	Run		
1	○	○	○
2		○	○
3			○

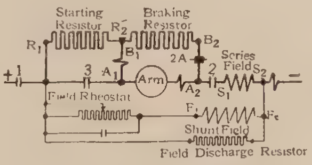
FIG. 274. Connections of Non-reversing Controller Panel of Fig. 273



Con	Off	Start		Run
1		○	○	○
2			○	○
1A	○			

FIG. 275. Connections of Non-reversing Panel with Dynamic Brake

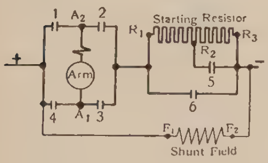
5. Reversing Control Panel with Dynamic Brake.—This panel, Fig. 278, is the same as Fig. 277, with the addition of a back contact on two of the line contactors. When both the forward and reverse contactors are open, the back contacts establish the dynamic brake circuit.



Con	Off	Dft	Start		Run
1			○	○	○
2		○	○	○	○
3				○	○
2A	○				

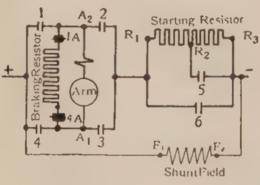
FIG. 276. Same as Fig. 275 with Addition of Drift Point Contactor

6. Reversing Control Panel with Dynamic Brake and Drift.—This panel is shown by diagram in Fig. 279, which is the same as Fig. 278 with the addition of another line contactor, *8*. This additional contactor is necessary only where the forward and reverse switches are double pole. Where single pole switches are used for reversing the motor, the drift position can be obtained by opening the reverse contactors, *2* or *3*, which



Con	For			Off	Rev		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○				○	○
6	○						○

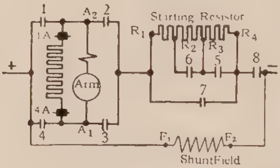
FIG. 277. Connections of Reversing Control Panel



Con	Rev			Off	For		
	Start			Bk	Start		
1					○	○	○
2	○	○	○				
3					○	○	○
4	○	○	○				
5	○	○				○	○
6	○						○
1A	○	○	○	○			
4A				○	○	○	○

FIG. 278. Same as Fig. 277 with Dynamic Brake

are not equipped with back contacts. The opening of one of the reversing contactors disconnects the motor from the line on one side and allows it to drift. The opening of the other line contactor completes the dynamic brake circuit and stops the motor. Since these controllers with reversing contactors are usually applied to large motors, the addition of the extra contactor on the other side of the line is frequently desirable, as it entirely disconnects the controller from the line. This disconnecting is not always necessary, as the opening of the knife switch will effect the same results. The knife switch, however, should never be opened under load, and the use of the extra contactor is sometimes desirable to clear a short-circuit, due to a ground. Items *3* and *6* provide for this extra contact, which may or may not be opened in advance of the dynamic brake contactor, depending upon whether or not a drift point is required.



Con	Reverse					Off	Forward				
	Start				Off	Ist	Off	Start			
1							○	○	○	○	○
2	○	○	○	○	○						
3							○	○	○	○	○
4	○	○	○	○	○						
5	○	○	○						○	○	○
6	○	○								○	○
7	○										○
1A	○	○	○	○	○	○					
4A						○	○	○	○	○	○
8	○	○	○	○				○	○	○	○

FIG. 279. Same as Fig. 278 with Addition of Drift Point Contactor

7. Field Rheostat Separately Mounted.—This rheostat, Fig. 280, can be used in connection with any control panel to provide adjustable speed control for the motor. It is desirable to have this field rheostat mounted separately from the panel, so that the operator does not have to place his hand near the main control circuit for operating it. It is also desirable to have the rheostat separately mounted so that it can be located in a convenient place and the control panel located on the machine tool or the wall where it is not readily accessible to unauthorized persons. Where the control panel is enclosed in a cabinet, the rheostat may be mounted in the cabinet with the handle extending to the outside. This requires the control cabinet to be located in an accessible place and is not convenient for many machine tool applications.

8. Push Buttons.—Push button stations may consist of one or more buttons arranged for manipulating a controller panel. They are usually applied to non-reversing panels and consist of a start and stop button. They may be located close to the field rheostat making a very compact and neat arrangement where the motor is operated for considerable periods of time.

9. Drum Reverse Switch.—A small switch is illustrated in Fig. 262. It may be used in connection with non-reversing panels to give reversing control. The same arrangement can be extended to larger switches when desirable.

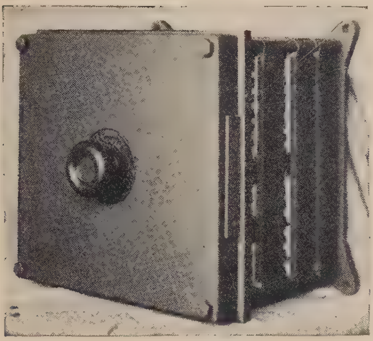


FIG. 280. Combined Master Switch and Field Rheostat

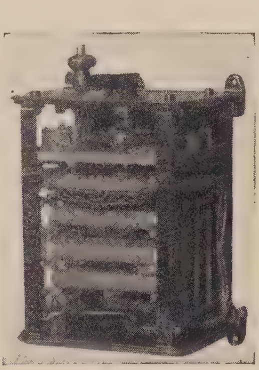


FIG. 281. Separately Mounted Field Rheostat

10. Master Switch and Field Rheostat Combined.—This arrangement, Fig. 281, is very convenient for lathes and similar tools, particularly where large motors are used. It is used in connection with one of the panels described in items *1* to *6*.

11. Reversing Switch and Field Rheostat.—This consists of a controller for reversing the direction of rotation of the motor, combined with a field rheostat and provided with contacts for operating one of the control panels, items *1* to *3*.

12. Reversing Controller with Field Rheostat.—Fig. 282 shows a small controller which is self-contained and can be used for adjustable speed motors on reversing service. A great many controllers of this type are used for motors up to ten horsepower capacity. It is easy to operate and proves quite durable for these motors. It does not require a controller panel. It is usually connected directly to the line through the knife switch and fuses.

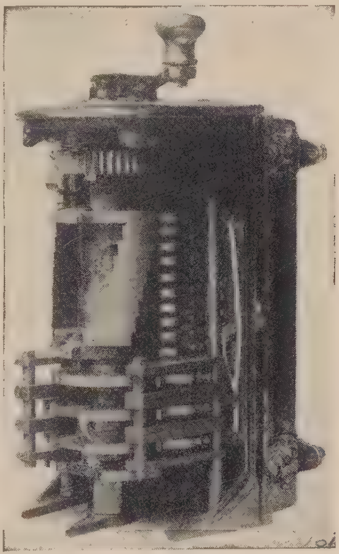


FIG. 282. Reversing Controller with Field Rheostat

Armature starting and field control

Where adjustable-speed motors having a considerable range of speed adjustment are used, it may be desirable to provide for starting with full field strength. This can be taken care of in several ways. Where the field rheostat is not mechanically connected to the master switch a convenient method is to use a small accelerator for short-circuiting the field rheostat during acceleration. This contactor can be made to operate automatically on a variation of current strength when desirable, but precautions should be taken to reverse the functions of this contactor or relay during regeneration. The relay, however, should short-circuit the field rheostat during dynamic braking. The amount of complication involved in the use of this relay will depend upon the size of the motor. For small motors, a small contactor held closed until the last accelerating switch is closed will be found very satisfactory and will eliminate most of the complication.

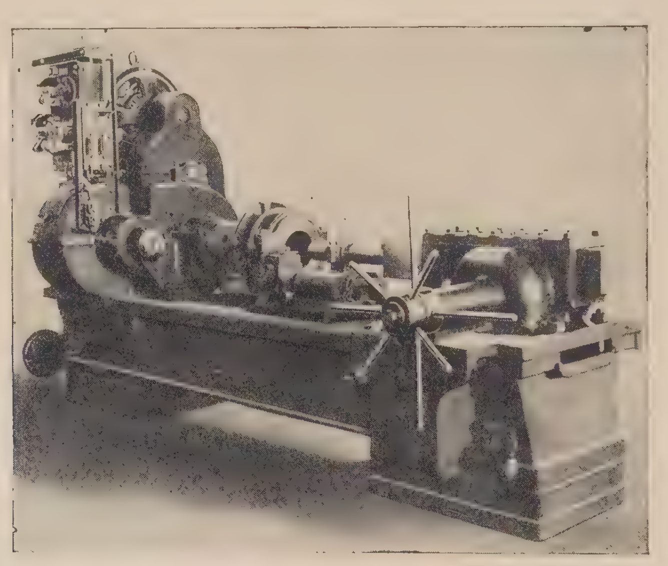


FIG. 283. Electrically-operated Turret Lathe

Equipped with old style control panel which has the field rheostat mounted with the contactors

The twelve items described above make a very convenient combination from a manufacturing standpoint, as well as from the standpoint of the user. The control panels, particularly item *1*, can be used for pumps, fans, and many forms of drive other than machine tools. Items *7* to *12* will be found useful for a variety of other applications. A manufacturing establishment requiring machine tool controllers has other apparatus operated by motors requiring control. It is therefore desirable to adopt a few standard controllers which have a wide application.

CONTROL APPLIED TO DIFFERENT MACHINES

A universal wood-milling machine which is motor-driven and provided with three control elements is shown in Fig. 260. At the base of the pedestal is mounted a cabinet containing the line switch and fuses together with a line and an accelerating contactor. On the inside of the cover, which can be locked in the closed position, is attached the wiring diagram and instructions. The knife switch is operated by a handle extending through the right-hand side of the cabinet. This knife switch is used only for disconnecting purposes and can be locked in the open position. Near the center of the table and located on either side of the operating levers of the machine is a field rheostat and a drum reversing switch. Both of these are covered to prevent contact with live parts.

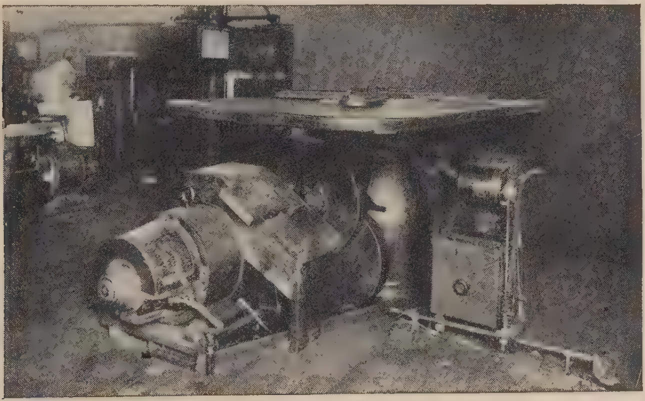


FIG. 284. Small Coil Winding Table

Operated by a reversing direct-current motor, with speed adjustment by field control and low-voltage protection with reset button

A radial drill is shown in Fig. 261. The same cabinet is used as in Fig. 260. The motor is non-reversing and the master switch is combined with the field rheostat. Fig. 284 illustrates a coil winding table. A number of these tables are located together and in the background can be seen the control cabinets for six tables. There is a handle on the outside of the box for opening the knife switch. A contactor with a blowout is in series with the motor; two other contactors short-circuit the starting resistor during acceleration. Each table is provided with a reversing drum controller and a field rheostat. The drum controller also serves as a master switch and is operated by a treadle. The push button, shown underneath the reverse switch in Fig. 284, is a reset button for low-voltage protection. In case of failure of voltage, the motor cannot be started again without pushing this button.

A turret lathe with an older form of control panel, in which the field rheostat is mounted on the panel with the contactors, is shown in Fig.

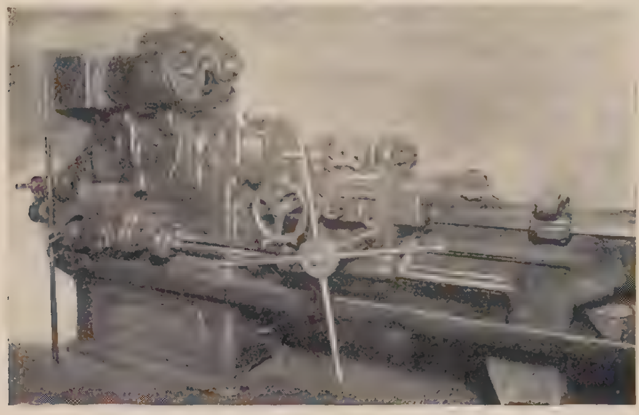


FIG. 285. Turret Lathe with Drum Controller

For reversing service. A field rheostat in the bottom of the controller is used to adjust the speed of the motor

283. While many of these panels are still in use, they may not comply with many safety requirements now enforced, as the operator can readily obtain a shock by carelessly placing his hands on a live part of the control.

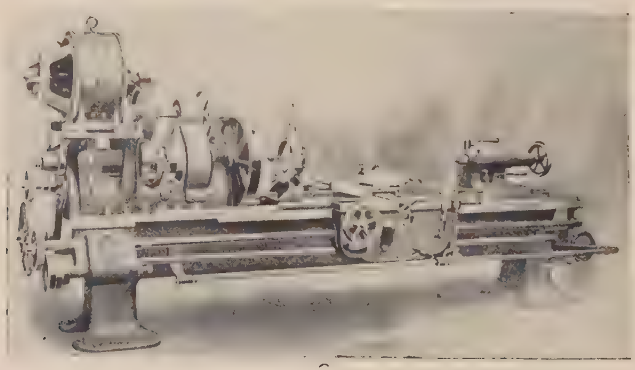


FIG. 286. Motor-driven Engine Lathe

The controller is operated from the spline shaft of the lathe

Fig. 285 represents the use of a drum controller arranged for armature starting and speed regulation by field control on a turret lathe. The controller is located close to the motor on the head of the machine, making a compact installation. The operator manipulating the machine stands within easy reach of this controller. The same form of controller is shown in Fig. 286 from the spline shaft of the lathe. This same arrangement can be used with the drum reversing switch and a separate control panel.

The methods of control illustrated in Figs. 260, 261 and 283 to 286 are very simple, consisting of a line switch which may or may not reverse the motor, together with suitable means for short-circuiting the starting resistance. A field rheostat may be added where adjustable-speed motors are used. Applications of this kind do not present any unusual control features. While they can readily be made up from the units described in the present chapter, the arrangement must be made to suit the particular design of machine. Some other applications, however, require considerably more study.

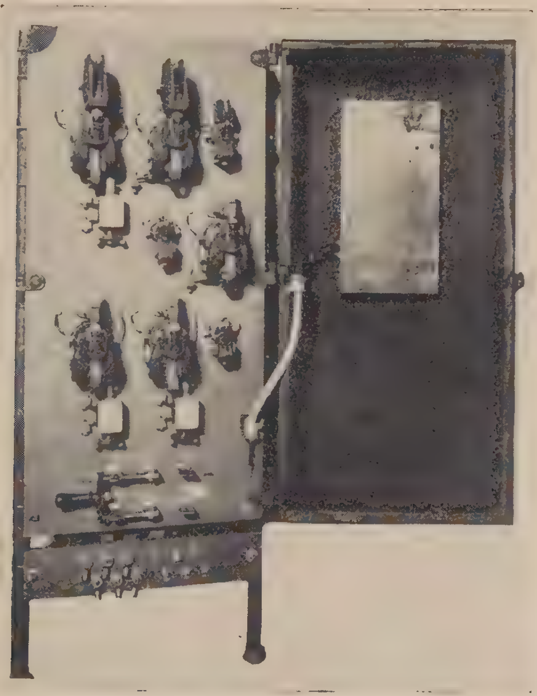


FIG. 287. Wheel-lathe Controller

When this panel is equipped with a cover, the field rheostat is mounted on the inside and operated from a handle on the outside

WHEEL LATHE

The application to the wheel lathe requires special consideration in order to obtain the maximum convenience in the operation of a machine designed for this particular purpose. The controller is illustrated in Fig. 287 and is operated by a push-button station having buttons marked *start, stop* and *slow.* This push-button station can be arranged for suspension by a flexible cord, and used as a pendant switch as shown in Fig. 288. The controller is non-reversing and is provided with current limit acceleration. If it is necessary to reverse the lathe for any purpose, it can be done by means of the knife switch shown at the bottom of the panel in Fig. 287. In the cover of the panel is located the field rheostat with the handle projecting to the outside. In turning up a large wheel, hard spots are often encountered requiring a slow cut over a part of the circumference. This can be obtained by depressing the button marked *slow.* "Inching" of the motor can be obtained by manipulating the *start* and *stop* buttons. This is very desirable in setting up work.

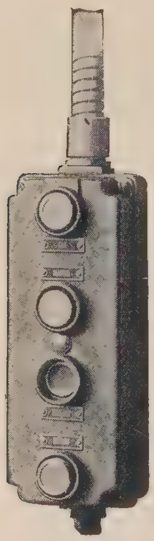


FIG. 288. Push Button Pendant Switch

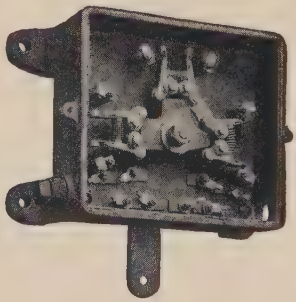


FIG. 289. Planer Master Switch

PLANER CONTROL

When a reversible motor is used for driving a planer, Fig. 290, the motor must be stopped and started quickly in the reverse direction. This requires a special motor, as well as a special controller. It is desirable to have a motor which gives a large torque with a small diameter of armature. The work done in reversing the platen of the planer consists in dissipating the stored energy in the moving parts until the platen comes to rest, and then storing energy in the moving parts during acceleration in the reverse direction. As the planer platen moves slowly, it has very little stored energy. Most of the energy stored is in the motor armature; hence the larger the diameter of the armature, the more work must be done in reversing. The requirement has resulted in the production of motors designed for this particular service and known as planer motors. These motors usually have a speed adjustment of 4:1 by shunt field control. Two field rheostats are used, one of which controls the speed during the cutting stroke and the other the speed during the return stroke. An arrangement of this kind is necessary so that the adjustment of the cutting stroke to suit the work will not interfere with the speed of return. During the stopping and acceleration period, both field rheostats are short-circuited automatically to give the motor the maximum torque during this part of the cycle.

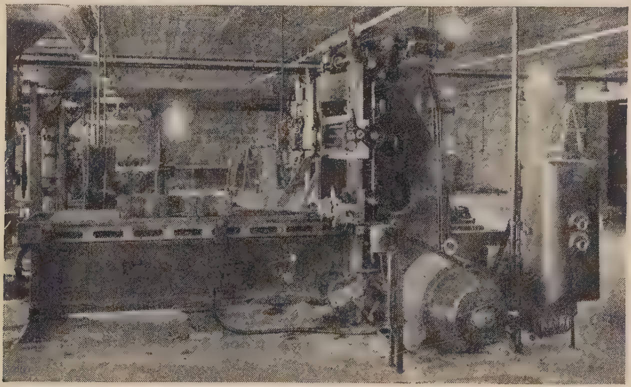


FIG. 290. Reversing Planer Controller

Operating a 4:1 speed direct-current motor. The handles for the field rheostats are shown in the cover of the controller to the right of the motor. One handle is used for adjusting the speed of the cutting stroke and the other for the return stroke. On the side of the planer is shown the master switch connected to the reversing gear operated by the platen of the planer. In front of the planer head is shown the pendant switch. Close to the main motor is a small drum reversing switch for controlling the motor which operates the tool carriage

A master switch, as shown in Fig. 289, is located on one side of the planer and operated by a shifting mechanism controlled by projections from the platen of the planer. These projections or "dogs," can be adjusted to limit the travel of the platen in each direction. The master switch is operated like the belt-shifting device on the old planers. Sometimes this master switch has been combined with a switch for reversing the direction of the motor. This caused considerable arcing in this switch and therefore much better service can be obtained by using magnet contactors for switching the motor circuit and using the master switch only for the purpose of controlling the small wire circuits to the contactors.

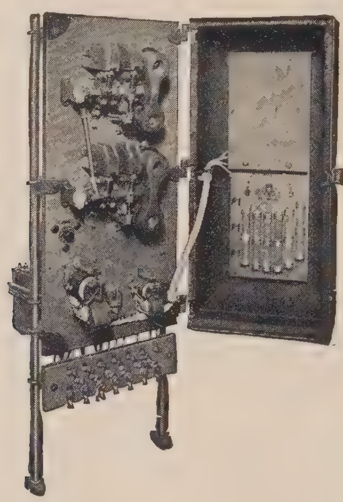
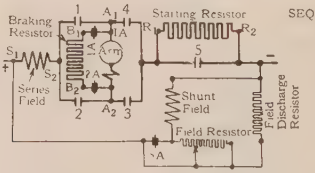


FIG. 291. Reversible Planer Controller

For use with adjustable speed direct-current motors. The field rheostats are mounted inside the cover and operated from the handles on the face of the cover as shown in Fig. 290. One rheostat is for the cutting stroke and the other for the return stroke

Controllers for planer service require rapid acceleration and therefore the starting resistance is short-circuited in one or two steps. Even with a 150-horsepower motor, starting in one step has been found to give the best results when the motor and control are adapted for such operation. When it is realized that the platen of the planer may pass through the



SEQUENCE OF CONTACTORS

Con	Cut		Bk	Off	Bk	Ret	
1						○	○
2	○	○					
3						○	○
4	○	○					
5	○						○
1A	○	○	○	○	○		
2A			○	○	○	○	○
5A		○	○	○	○	○	

FIG. 292. Connections of Reversing Planer Motor Control Panel. Shown in Fig. 291

cutting and return stroke, making a complete cycle in six or seven seconds, the speed of stopping and accelerating is very important.

It is desirable to provide for an emergency stop in case of failure of voltage. A common method of obtaining this is to short-circuit the motor armature through a resistance and at the same time short-circuit the field rheostat. This causes the motor to operate as a self-excited shunt generator. Usually there is sufficient residual magnetism in the motor field to make this operation satisfactory. Where it is necessary to take extra precaution, a mechanical brake with a magnetic release can be mounted on an extension of the motor shaft. The magnet windings are energized by line voltage to release the brake, therefore on failure of line voltage the brake sets. The brake wheel adds to the stored energy of the armature of the motor; the magnet winding consumes energy while the planer is operating; the brake itself takes up extra room and requires a special extension of the motor shaft. For these reasons, the

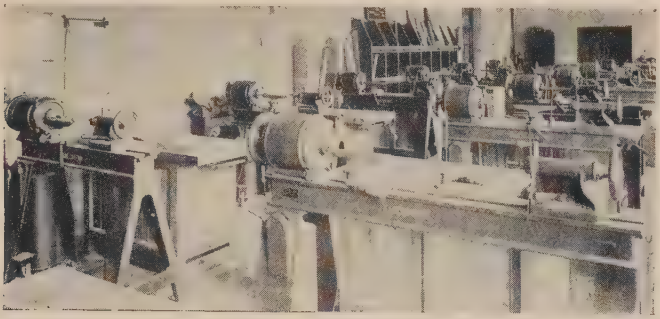


FIG. 293. Group of Wood-turning Lathes

Equipped with four-speed, squirrel-cage motors which are totally enclosed and operated by drum-type controllers. These controllers are located back of the leg of the lathe with their operating handles near the head of the lathe

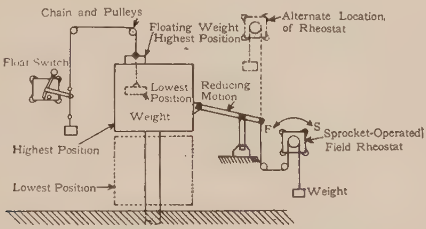


FIG. 294. Arrangement of Controller for a Hydraulic Accumulator

For use in forge shops

brake is not used except where it is important to make a positive emergency stop.

Fig. 291 shows a standard control panel, and Fig. 292 a wiring diagram of a controller which has had a wide application.. This panel provides for dynamic braking by connecting the motor as a self-excited shunt generator in case of the failure of line voltage. The direction of rotation of the motor is controlled by double-pole magnetic contactors, shown at the top of the panel in Fig. 291. The contactors are interlocked by a steel rod, which prevents both directional switches being closed at the same time. Each directional switch is provided with a back contact shown as *1A* and *2A* on the diagram in Fig. 292, which complete the dynamic brake circuit. When either directional switch is closed, this back contact is opened, disconnecting the brake circuit. The shunt field remains connected across the line when the planer is being operated. It is provided with two field rheostats, only one of which is shown on the diagram, one rheostat being for forward operation and the other for reverse operation. The particular rheostat in use is selected by the master switch. Connections are arranged so that these field rheostats are short-circuited during acceleration by means of a contact attached to the accelerating contact *5* in Fig. 292. The small contactor in the lower right-hand side of the panel is used for no voltage protection. On failure of voltage, the planer is stopped and cannot start again until the reset button is operated.

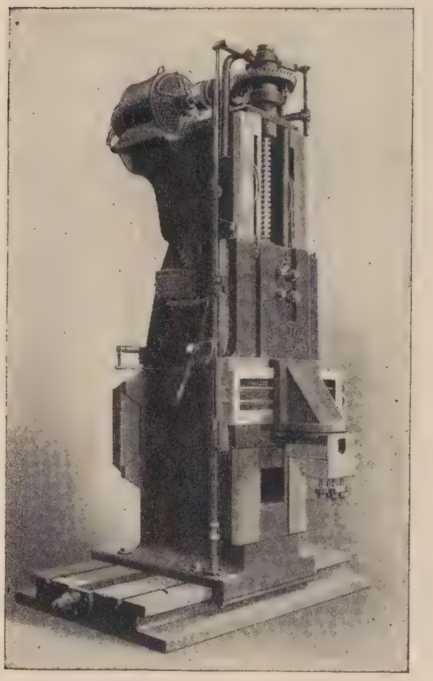


FIG. 295. Electrically-operated Slotter Driven by a 20-hp., 4:1 reversing planer motor. The controller used is similar to that shown in Fig. 291

In addition to a master switch operated by the platen of the planer, a pendant switch, Fig. 288, may be provided having push buttons marked *master, pendant, cut* and *return.* When the *master* button is pressed, the master switch controls the operation; when the button marked *pendant* is pressed, the operation is controlled by depressing either the *cut* or *return* button. It is necessary to hold these buttons down, as the motor will come to rest automatically if the operator releases the pendant switch. In addition to these buttons, the reset button may be included in the pendant switch. The use of this pendant switch adds greatly to the convenience of the operator in setting up his work.

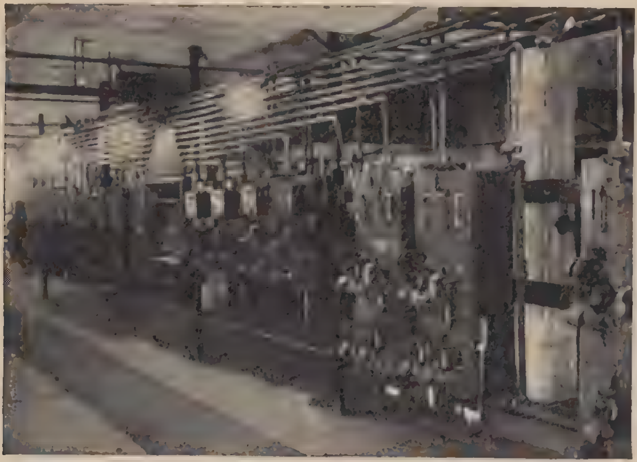


FIG. 296. Method of Grouping Machine Tool Controllers

On either side of the distributing cabinet. If this row of controllers is protected by a screen, it will meet safety requirements, as the operation of the motor is by a push-button or master switch and the operator is not required to handle any apparatus on the control panel

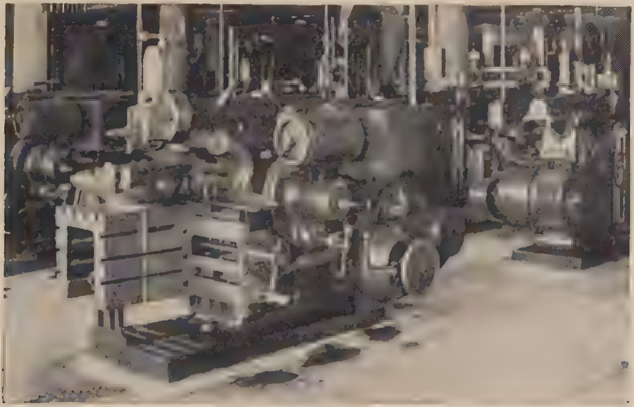


FIG. 297. Motor-driven Shaper with Drum Controller

Having armature starting and field regulation, showing a neat and compact arrangement for electric drive

As an added precaution, the master switch is wired so that both sides of the operating coils are disconnected when the switch is in the *"off"* position. In designing controllers, it is desirable to eliminate as many interlocks and relays as possible.

The planer type of control has been used with slotters, Fig. 295, planers, shapers, key seaters, and gear-cutting machinery. Each of these applications differs to some extent from the standard planer, and it is not desirable to apply a standard controller without an investigation. This is particularly true in the application to gear-cutting machinery. Some of these machines oscillate the gear, and at the same time move the tool forward and back. If the gear is very heavy, the rapid oscillation of this gear imposes a severe duty upon the whole equipment and care must be taken to prevent seriously racking the apparatus.

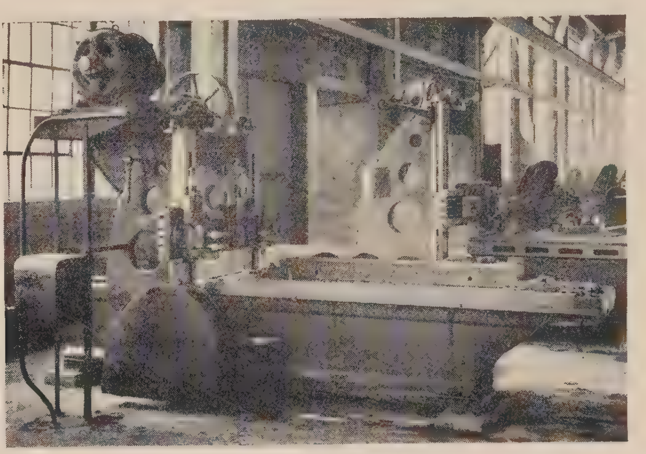


FIG. 298. Planer with Autostarter and Continuously Operating Alternating-current Motor

The reversing of the platen is done by shifting belts. This makes a very good arrangement for alternating-current drive. The guard on the side of the planer serves to prevent injury to the operator

A modification of the reversing planer equipment is the non-reversing equipment. The direction in which the platen travels is changed by mechanical means and the motor permitted to run continuously in one direction. Provision, however, is made for changing the speed of this motor by adjusting the field so that a different speed of platen can be used for the cutting and return strokes. This equipment permits the use of a standard motor, but in many respects is not as economical as the reversing equipment and sometimes difficulty is experienced with the mechanical reversing drive, due to wear. Such an arrangement, however, lends itself readily for attachment to standard planers, formerly designed for line shaft drive.

The development of the wheel lathe and the planer controllers shows the advantage of electric drive for machine tools where a proper equipment is designed and the machine tool built for such an equipment. Many special machine tools are being designed for motor drive; if a proper study of the conditions is made, present experience in this art enables the electrical engineer to provide a suitable equipment to meet the most exacting conditions.

SUMMARY OF CHAPTER XXVI

Most machining tool controllers may be classified as follows:

(1) non-reversing controller;
(2) non-reversing controller with dynamic braking;
(3) non-reversing controller with dynamic braking and drift;
(4) reversing controller;
(5) reversing controller with dynamic braking;
(6) reversing controller with dynamic braking and drift;
(7) field rheostat separately mounted;
(8) push buttons;
(9) drum reverse switch;
(10) master switch and field rheostat combined;
(11) reversing switch and field rheostat;
(12) reversing controller with field rheostat.

A special motor and controller are required for the reversing planer. As the motor must be accelerated, stopped, and reversed quickly, the armature diameter is kept small, the mechanical brake is usually omitted, and dynamic braking is used.

CHAPTER XXVII

CALENDERING AND PRINTING MACHINES

Importance of personal safety—two voltage system versus the four to one speed range motor—two motor systems—gear changing system—push button control—safety features.

Control equipment providing a slow operating speed of about one-twentieth of the normal speed is used in setting up some machines preparatory to the commercial run; for instance, in a paper or rubber calender, where the paper or rubber must be threaded between the calender rolls by hand. Unless these rolls turn at a very slow speed, the operator is in danger of injury. Another such application is the cloth printing machine in textile mills. The cloth is threaded through the machine in a manner similar to a calender and in addition, it is necessary to see that the printing registers properly before operating at normal speed.

The different applications require minor changes in details but the underlying principles are the same. Recent legislation has been enacted in several states requiring the live parts of the control equipment to be inaccessible to unauthorized persons. This is tending very strongly to increase the use of remote control from push-button stations or master switches. The push-button controller is the most desirable but costs more. In the past, it has been selected in the main on account of its convenience. In the future, the question of personal safety to the operator will be an important additional factor in the selection of this type of control.

In equipments of this kind as a rule, the torque required from the motor is constant. The load is mostly friction and therefore steady. In paper calenders the quality of the stock and the pressure between the rolls also affect the load, but this load remains approximately uniform for any particular combination. The load on rubber calenders is more variable on account of the numerous operations performed by the same machine. It is affected considerably by the amount of rubber in the rolls. The variation in the torque of the motor is a very important factor in designing a suitable control for operation at slow initial speeds.

After the machine has been made ready to operate, it is accelerated smoothly to the proper operating speed. Most of these applications require a large number of economical operating speeds, which are obtained by changing the field strength of the direct-current motor, or if an alternating-current motor is used, the resistance of the secondary circuit is changed.

In some applications, a two voltage direct-current circuit is provided, usually 115 to 230 volts, shown by diagram, Fig. 308. The double-voltage system reduces the speed range required from a motor by field adjustment and, therefore, decreases the first cost of the motor. The disadvantage of this system is the extra wire required and the additional complication in the generating equipment. In some applications, a rotary converter is used to change the power from alternating to direct-current.

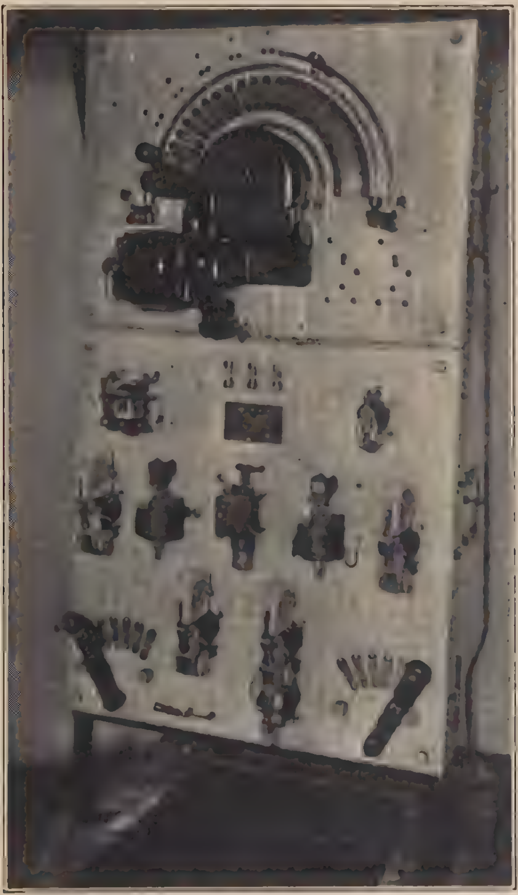


FIG. 299. One Motor Single Voltage Control

This converter can readily be arranged to give both 115- and 230-volt, three-wire power circuits. In most cases, this converter is located close to the machinery and the extra expense of wire is small.

The cost of a 4:1 adjustable speed direct-current motor, as compared with a 2:1 motor, depends to a considerable extent upon the commercial demand for this 4:1 motor. These motors are built in considerable quantities up to 50 or 75 horsepower, and for such sizes it is usually more economical to use a 4:1 motor than a 2:1 and a double voltage system of control. For larger sizes, the reverse may be true. This situation is, of course, undergoing continual commercial change and a decision should only be reached after a careful investigation of the apparatus available.

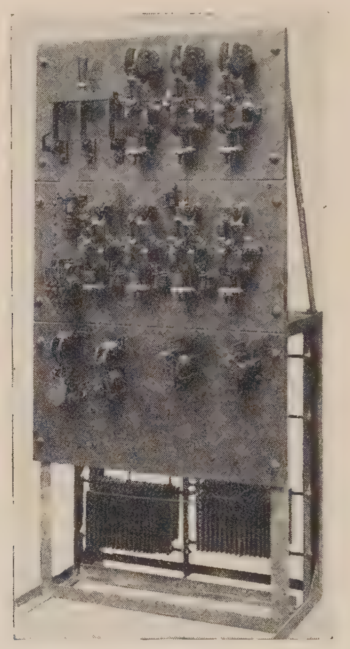


FIG. 300. Single Motor and Double Voltage Control

The speed control over the normal operating range presents no problems different from those previously described. The problem which makes this class of control different from others, is the method of obtaining a very slow operating speed for making up the machine. The starting or threading speed for direct-current equipments may be obtained by using resistors in series and in shunt with the motor armature.[1] Where the size of the motor is small or the minimum operating speed comparatively high, this method is economical and frequently used.

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[1] This method of speed control was described in Chapter XI.

For large motors or where a wide difference exists between the slow speeds for threading purposes and the maximum operating speeds, four methods of control have been applied:

1. This arrangement can be used for either alternating or direct current. It consists in using a small auxiliary motor geared to the main drive to give the proper slow speed with the small motor operating near its normal speed. This motor is started up and controlled in the usual manner. After the machine has been made up, the main operating motor is connected to the line and accelerates the machine to its normal operating speed. At the same time, the small motor is disconnected from the line and automatically uncoupled from the machine. The schematic diagram for a direct-current motor is shown in Fig. 303 and for an alternating-current motor in Fig. 304.

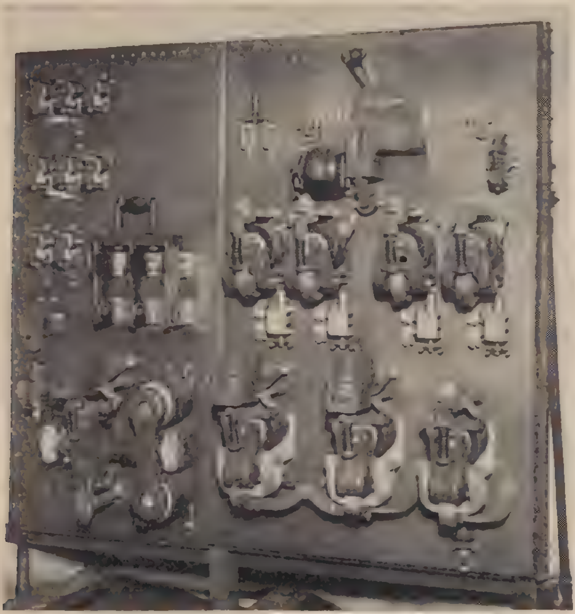


FIG. 301. Single Motor and Double Voltage Control

The field rheostat is operated by a push button controlled motor

2. This scheme is applicable to either alternating or direct-current motors. It is similar to *No. 1*, except that both the main motor and the auxiliary motor are started together, the motors being geared together.

The resistor in series with the main motor is adjusted to give less than the required speed of the machine. The additional speed is obtained by loading the auxiliary motor. Since this auxiliary motor operates close to its normal speed, its operation is quite stable and it readily adapts itself to any change in the load without a material change in its speed. If the equipment is operating at the required speed and the load increases, the machine tends to slow down. A small change in the speed of the machine makes a large change in the speed of the auxiliary motor and materially increases the load on this motor so that it supplies the additional torque required with only a slight decrease in speed. If the load is reduced instead of increased, a slight increase in the machine speed will cause a

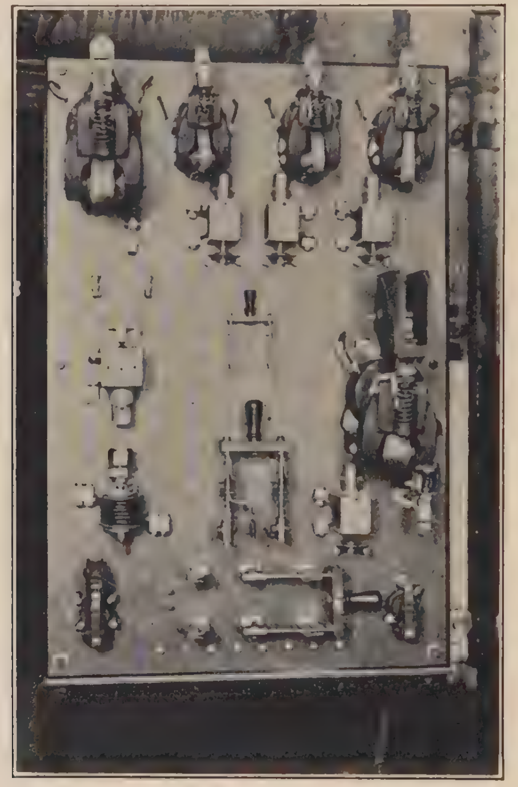
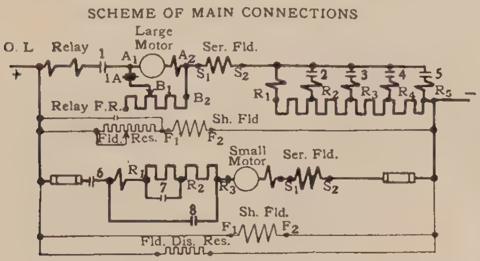


FIG. 302. Controller for a Single Motor with Adjustable Armature Series and Armature Shunt Resistance

This controller is represented diagrammatically in Fig. 310. The contacts in the lower left corner are those controlled by switch *3* and the contacts in the lower right corner are those controlled by switch *4* considerable increase in the speed of the auxiliary motor, which materially reduces the load on this motor and compensates for the difference in



SEQUENCE OF CONTACTORS

Contactor		Off	Run							Field Cont.	
Large Motor	1				○	○	○	○	○	○	○
	2					○	○				
	3						○	○			
	4							○	○		
	5								○	○	○
	F.R.				○	○	○	○	○		
	1A	○									
Small Motor	6		○	○	○						
	7			○							
	8				○						

FIG. 303. Control Scheme for Operation Over a Wide Range of Speeds

A large motor and small motor are used. The small motor operates the machine at minimum speed and is cut out of circuit when the large motor is used for driving the machine at normal speed. After all the contactors have closed, during acceleration, the motor is gradually brought up to the speed corresponding to the rheostat setting, by the field relay *FR*

torque required by the machine. Since the auxiliary motor acts only as a stabilizer, it can be smaller than where it alone is used to drive the machine at the slow speed. The schematic diagram of this control, Fig. 305, differs from the former diagrams in that the main motor is in circuit during the start. After the machine is made up, the main motor accelerates it to the normal operating speed and the small motor is dis-

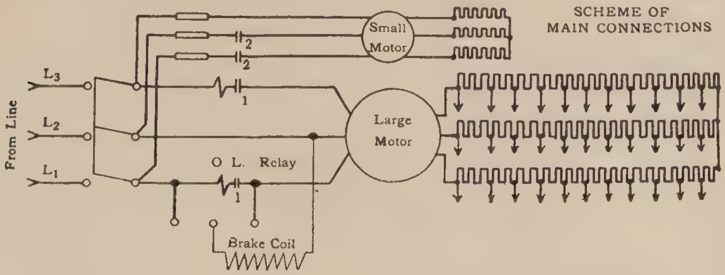
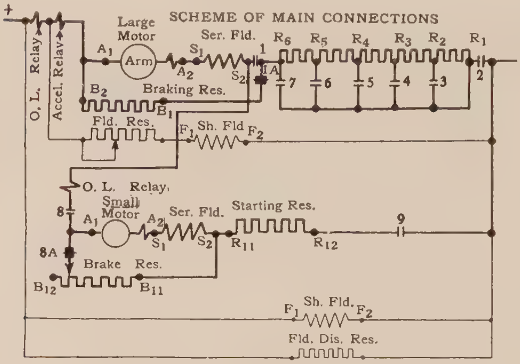


FIG. 304. Control Scheme for Alternating-current Motors

The small motor is connected to the line by contactor *2* and the large motor by contactor *1*. The resistors in the small motor circuit are adjusted to give the proper minimum speed. The large motor may or may not be connected to the line, while the small motor is operating the machine. The speed of the large motor is adjusted by changing the resistors in the secondary with a drum controller. The small motor is disconnected when the large motor begins to accelerate the machine connected from the line and disengaged from the gearing so that it remains at rest during normal operation.



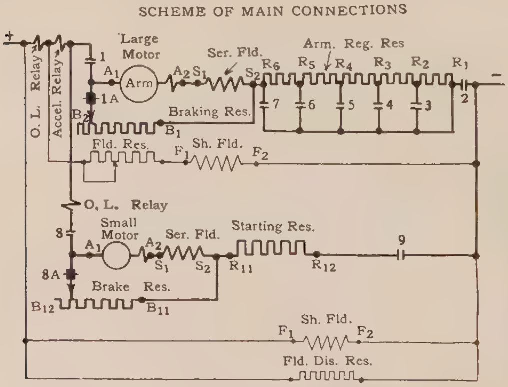
SEQUENCE OF CONTACTORS

Con-tactor	Off	Inch	Increase → ← Decrease								Field Contr	
1				○	○	○	○	○	○	○	○	○
2				○	○	○	○	○	○	○	○	○
3						○	○					
4							○	○				
5								○	○			
6									○	○		
7										○	○	○
8		○	○									
9		○	○									
1A	○	○										
8A	○				○	○	○	○	○	○	○	○

FIG. 305. Modification of the Scheme Shown in Fig. 303

Both the small motor and the large motor are connected to the line during the slow-speed operation. The diagrams are essentially the same, except for the sequence of the contactors

3. The third scheme is applicable only to direct-current motors, Fig. 306. The armatures of these two motors are connected in series, and they are connected together through gearing for the slow speed. Both motors are started at the same time, the small motor running close to its normal speed. Its armature sets up a counter e.m.f. which absorbs most of the line voltage available for the main motor. A small change in speed

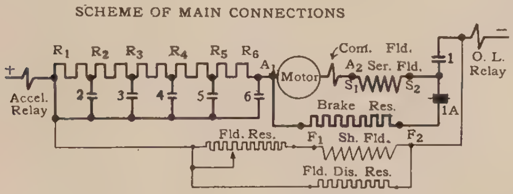


SEQUENCE OF CONTACTORS

Con-tactor	Off	Inch	Increase → ← Decrease								Field Contr.	
1			○	○	○	○	○	○	○	○	○	○
2				○	○	○	○	○	○	○	○	○
3						○	○					
4							○	○				
5								○	○			
6									○	○		
7										○	○	○
8		○	○									
9		○	○									
1A	○	○	○									
8A	○			○	○	○	○	○	○	○	○	○

FIG. 306. Modification of the Scheme Shown in Fig. 303

The main motor and small motor have their armatures connected in series for the minimum speed. The small motor is disconnected when the large motor accelerates the machine to normal operating speed of the machine causes this auxiliary motor to alter its counter e.m.f. which makes a considerable change in the voltage across the main motor and adjusts the total torque for the two motors with only a very small change in speed. After the machine is made up, the small motor is disconnected from the line and replaced by a resistor, which is gradually cut out to accelerate the large motor to the normal operating speed.

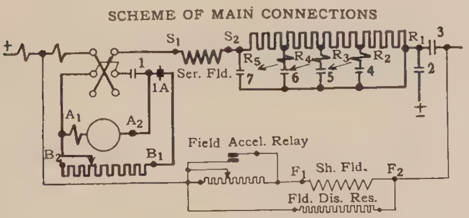


SEQUENCE OF CONTACTORS

Con-tactor	Off	Inch	Increase → ← Decrease							Field Contr	
1		○	○	○	○	○	○	○	○	○	○
2				○	○						
3					○	○					
4						○	○				
5							○	○			
6								○	○	○	○
1A	○										

FIG. 307. Control Scheme for Use with a Mechanical Gear Changer To give the slow speed operation

4. The fourth scheme, Fig. 307, consists in a double set of gearing connected by some form of friction or magnetic clutch. The machine is operated by one motor, which starts by driving the machine through the reduction gear. After the machine has been made up, the large motor is gradually transferred from the low gearing to the high gearing by means of the clutch. A considerable number of mechanical devices have been placed on the market for effecting this change in speed gradually without shock or jar to the drive. No attempt will be made to describe these devices in detail, as they differ widely for different classes of service.



SEQUENCE OF CONTACTORS

Con-tactor	Off	Steps							Steps					13-19
		1	2				3-11	11½	12					
1		○	○	○	○	○	○	○	○	○	○	○	○	○
2		○	○	○	○	○	○							
3									○	○	○	○	○	○
4			○	○	○					○	○	○		Field Control
5				○	○						○	○		
6					○							○		
7						○	○						○	○
F.R.		○	○	○	○				○	○	○	○		
1A	○													

FIG. 308. Control Scheme for Operation from Two Voltages

The lower voltage is between positive and neutral and the higher between positive and negative. Resistors are provided both in series and shunt with the armature to give the slow-speed operation at the minimum voltage. A two-pole, double-throw knife switch is shown for reversing the armature if occasion should require. This switch is operated only when the motor is disconnected from the line. Steps 3 to 11 are field control at the low voltage, and 13 to 19 are field control at the high voltage

The selection of the best scheme for any particular drive is determined largely by the first cost and maintenance, which is in turn influenced by the commercial apparatus available. An analysis of each particular problem should be made. A description of a push-button controller of this general type will, in the main, cover the manual and semi-automatic controller. Panels for several different automatic controllers are shown. These panels consist of a power-driven master switch having sliding contacts, the contact arm being moved either by a small motor or a magnet. This motor or magnet is controlled by a set of push buttons. The movement of this master switch controls the circuit to the main and auxiliary motors, partly through magnetic contactors and partly by direct contact. The power-operated master switch may be replaced by a drum type or face plate master switch operated manually. The motor-operated switches shown are provided with a handle for operating the face plate by hand, when occasion requires it, and move in a clockwise direction for an increase in speed. The solenoid-operated master switch moves downward for increasing the speed of the machine and upward for decreasing the speed. The acceleration of the main motor may be controlled by any of the usual methods of automatic acceleration.[2]

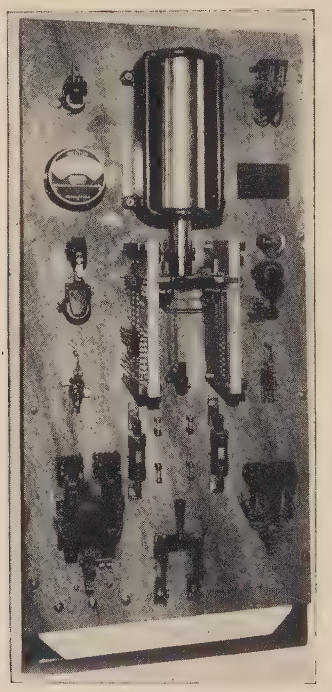


Fig. 309. Two Motor, Full Automatic Direct-current Controller

For remote control by push buttons

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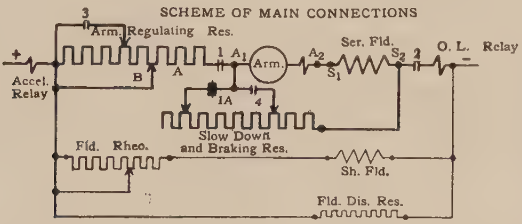
[2] Described in Chapters VII, VIII and IX.

Fig. 314 shows a typical push-button station consisting of five buttons marked *safe, run, fast, slow,* and *inch.* Several of these stations may be used for one controller. If we assume that this push-button station is connected to one of the motor-operated panels controlling a main and auxiliary motor supplied with direct-current power, the operation of the system will be as follows:

The push button marked *run* at all the stations must first be depressed, as the control is inoperative if any of the buttons marked *safe* are depressed. After all of the *run* buttons are depressed, the machine may be started by pressing the *fast* button. As long as this button is held down the controller gradually increases the speed of the machine. When the desired speed is reached, the button is released. This stops the pilot motor or solenoid and permits the machine to operate at that particular speed. If this speed should prove too fast, the button marked *slow* is depressed, which causes the speed of the machine to decrease. In starting up, the *fast* and *slow* buttons may be manipulated until the desired "make ready" speed of the machine is obtained. After the machine has been made ready, the *fast* button is again depressed and the motor accelerated to the desired operating speed. Automatic means may be provided for stopping the pilot motor when the desired speed is reached, or this may be left to the discretion of the operator.



SEQUENCE OF CONTACTORS

Contactor	Off	Inch		Incr → Decr ←		
1		○	○	○	○	○
2		○	○	○	○	○
3		○		○		
4			○		○	
1A	○					

FIG. 310. Control Scheme for Automatic Acceleration with Face Plate Rheostat

This is a controller having both armature, series and shunt resistors for the minimum speed, together with field control for giving the various operating speeds. This control is usually applied to smaller motors or where the speed reduction is medium. A photograph of this controller is shown in Fig. 302. The series resistor is short-circuited in steps by the motor operated handle designated as *B* on the diagram. At the start, *B* is at the extreme left. This gives so much resistance in series that the motor might not be able to overcome the starting friction. To obviate this, contactor *3* is closed on the first position, and is automatically opened when the motor starts to rotate, leaving the full resistance in series. Contactor *4* closes when *3* opens, giving the lowest operating speed.

If it is desirable to move the machine only a short distance in order to "spot" a particular part of the apparatus, the button marked *inch* may be pressed. This moves the machine at a very slow speed and stops it as soon as the button is released. This method of operation is more expeditious than using the *fast* and *slow* buttons, where it is desired to operate the machine only momentarily.

In order to stop the machine, the push button marked *safe* is depressed. This opens the main circuit to the motors and, where direct current is used, it applies a dynamic brake. Where alternating-current power is used, it releases a magnetic brake. These brakes are set to bring the machine to rest as quickly as safety will permit, in order to decrease the effect of any accident which might occur while operating. The quick stop is not required under normal conditions, but it is always a convenience to bring the machine to rest with as little delay as possible, even if no accident should occur. When the *safe* button is depressed, the pilot motor is connected so as to move the master switch back to the starting position.

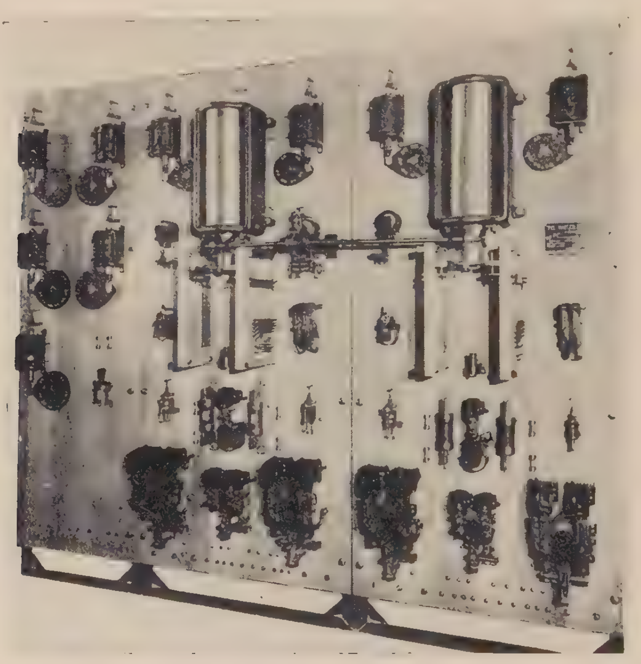


FIG. 311. Double Two Motor, Direct-current Controller
Arranged to operate as a single unit

A number of safety features are employed in these controllers, as follows:

1. If any *safe* button is pushed, the machine cannot be started again until the *run* button at that particular push button station has been pushed.

Provision can be made for locking the *safe* button in the depressed position so as to prevent the machine from being started while an attendant is working on the interior of the machine.

2. When the *safe* button is depressed, the machine cannot be started up again until the master switch has returned to the off position.
3. A current limit relay can be provided to stop the acceleration temporarily when the current exceeds a fixed value. This provides current limit acceleration and guards against the pilot motor operating the arm faster than the main motor can accelerate the machine.

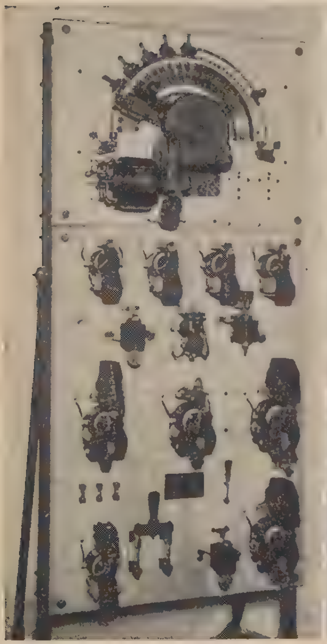


FIG. 312

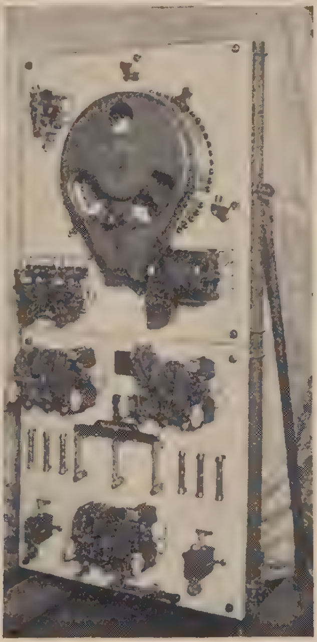


FIG. 313

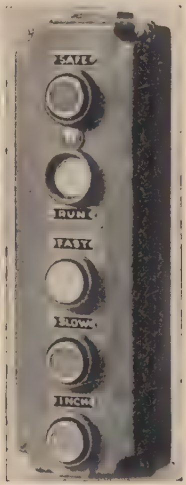


FIG. 314

FIGS. 312 and 313. Two Motor, Full Automatic Controllers

Fig. 312 is for direct current and Fig. 313 for alternating current. Both are for remote control from push button stations

FIG. 314. Push Button Control Station

4. An overload relay is provided for disconnecting the motor in case of overload.
5. Low-voltage protection is provided so that, on failure of power, the machine will not start again without the action of an attendant.
6. Mechanical means are provided for disconnecting the operating lever from the pilot motor and moving it by hand, if such an emergency should arise. This converts the controller from full automatic to manual control.

It can readily be seen from the description of the automatic controller that either all or a part of the automatic features may be replaced by manual control to reduce the cost.

SUMMARY OF CHAPTER XXVII

Some machines, as paper calenders, rubber calenders, printing presses, and cloth printing machines, require at starting (for threading material between rolls, etc.) a speed much lower than the normal operating speed. The load is usually of a friction nature, requiring a constant motor torque.

A wide range of speed (operating usually four to one) is required. This may be obtained by field adjustment or by a two voltage system. The latter reduces the amount of field adjustment necessary, hence lowering the first cost of the motor, but a third power wire and more complicated generating equipment are required. Whether this system or one using a four to one adjustable speed motor is cheaper depends upon the size of the motor and motor costs at the time.

Protection of the live parts of the control, to prevent being touched accidentally, is in some States required by law.

The following are four schemes for obtaining the low speed at starting and changing to the normal operating speed:

(1) A small auxiliary motor drives the machine at low speed while it is being made up. The large motor is then connected to the line and accelerated to normal speed, the small motor being automatically disconnected from the line and disengaged from the gearing.

(2) Both motors are used at starting, being geared to the machine. The main motor's speed is reduced by armature resistance to less than the threading-in speed required, being increased to this point by the torque of the small motor, which is operating at nearly its normal speed. When the machine is accelerated to normal speed the small motor is uncoupled and disconnected. Here the auxiliary motor, not being used to drive the machine alone, may be smaller than in (1).

(3) Both motors are used at starting, being geared to the machine. Their armatures are connected in series. The small motor is operating at approximately normal speed, its counter e.m.f. consuming most of the line voltage, and the large motor hence operates at a low speed. The small motor is then disconnected and uncoupled and the large motor accelerated to normal speed.

(4) The machine is driven by one motor, being started at a low speed by means of a reduction gear, and transferred to the high speed gearing by means of a friction or magnetic clutch.

Push Buttons: The safe button stops the motor and opens the control circuit (if a stop button is furnished the safe button merely opens the control circuit) so that the motor cannot be started until the run button is depressed. The run button closes the circuit opened by the safe button, making it possible to start the machine.

The fast button starts the motor and gradually increases its speed, as long as depressed, until normal speed is reached, or until the button is released. Similarly, the slow button reduces the speed.

The inch button operates the machine at a low speed as long as depressed.

CHAPTER XXVIII

PAPER MACHINES

Paper machines—cylinder type—Fourdrinier type—steam drive—single motor drive—sectional drive—synchronous motor type regulation—regulation by step type field rheostat—regulation by intermittent type field rheostat.

The application of motor drive to the individual sections of paper machines is very interesting as it brings out certain features in motor control that are relatively new and will probably have a wider application in the future. The solution of this problem has been difficult and at this time is still undergoing development. In addition to the paper machine this system of control is applicable to the tandem operation of rubber mills, certain forms of textile machinery and probably tandem rolling mills for metal. Control for these applications remains to be developed and will depend much on the cost of installation and the benefits that may result to offset the increased cost.

In order to understand the reason for a control system of this kind it will be necessary to know something of the paper machine itself. There are two general types of paper machines. One of these types is the Fourdrinier machine upon which are made the comparatively light weight papers such as news paper, book paper, etc. Fourdrinier machines may operate at a paper speed as low as 50 feet per minute. They may operate at a maximum speed of 1200 feet per minute.

The second type of paper machine is the cylinder machine. It is used to make the heavier papers such as cardboard, box paper, containers, etc. Its operating speed may be as low as several inches per minute and as much as 300 feet per minute.

The fundamental difference between the Fourdrinier machine and the cylinder machine is, that on the Fourdrinier machine the sheet of paper is formed upon a screen called the Fourdrinier wire, whereas on the cylinder machine the sheet is formed on cylinder molds. The Fourdrinier wire is a fine screen which operates around two rolls and is driven by one of them called the couch roll. The pulp stock solution is deposited on this wire in a thin even covering and the paper sheet is formed by extracting the water both by gravity and vacuum boxes over which the wire slides. In the case of the cylinder machine the pulp stock solution

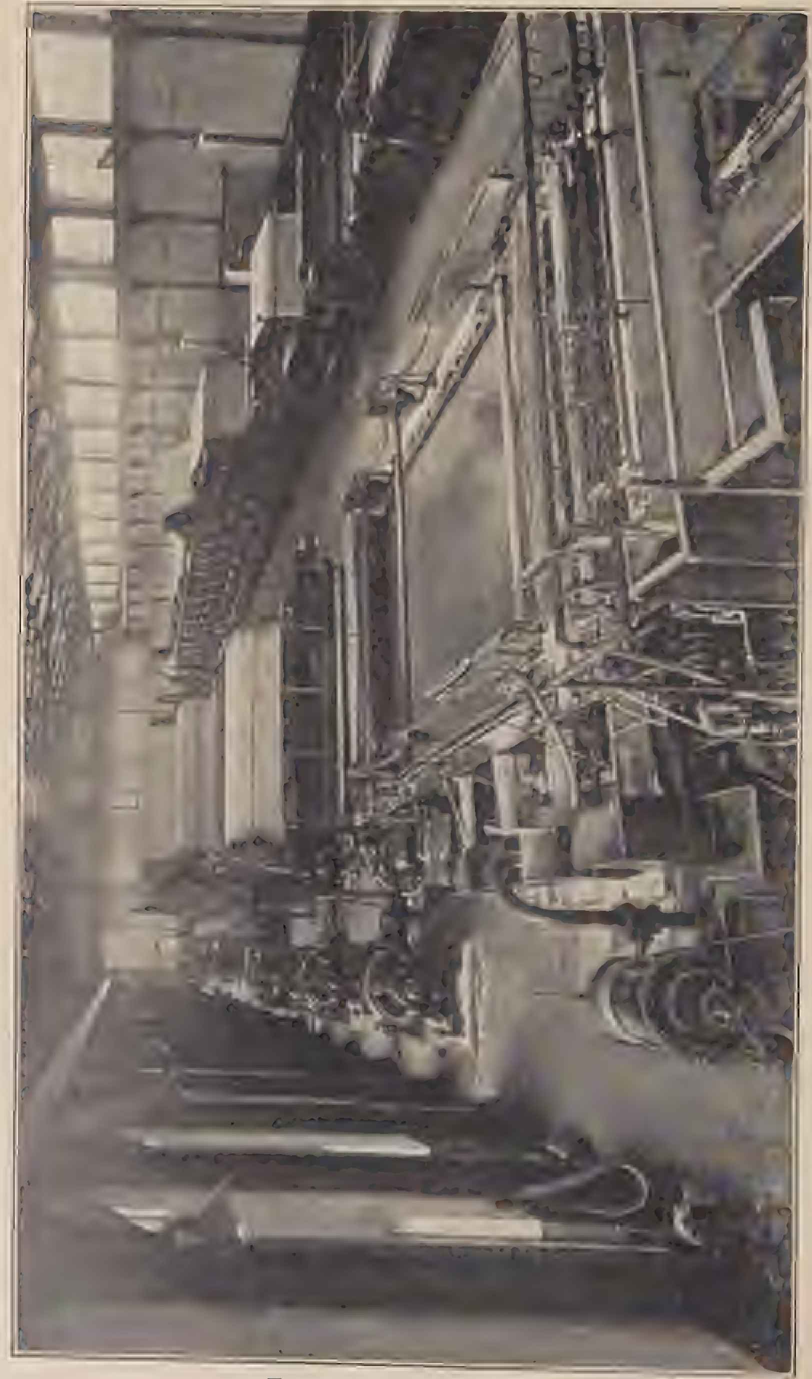


FIG. 315. Paper Machine

is deposited upon the face of one or more rotating screens each of which adds a thin layer of pulp stock to a felt, thereby building up a sheet of any desired thickness.

A paper machine is made up of sections (Fig. 315), through which the paper passes during the manufacturing process. The number of sections of a machine depends upon the kind of paper to be made. Most machines are made up of one couch or cylinder section, one or more presses, one or more dryers, one or more calenders and a reel. From the couch section the paper passes into the presses where more water is removed by pressure between the press rolls. The drying process is completed by passing the paper through the steam heated rolls of the dryer sections, smooth finish is given the paper by the calender rolls and the finished paper is wound into rolls by the reel.

For many years the various sections of a paper machine have been driven from a common line shaft which in turn was driven by a steam engine or a single motor. This type of drive is still common today and when a motor is used, it is known as a single motor drive.

When each section of a paper machine is driven by an individual motor most of the line shafting, gearing and belting used with the single drive is eliminated. The machine itself is easier and safer to operate. An installation of this kind is known as a sectional motor drive.

The electrical equipment for a complete paper machine drive of this type consists of the following:

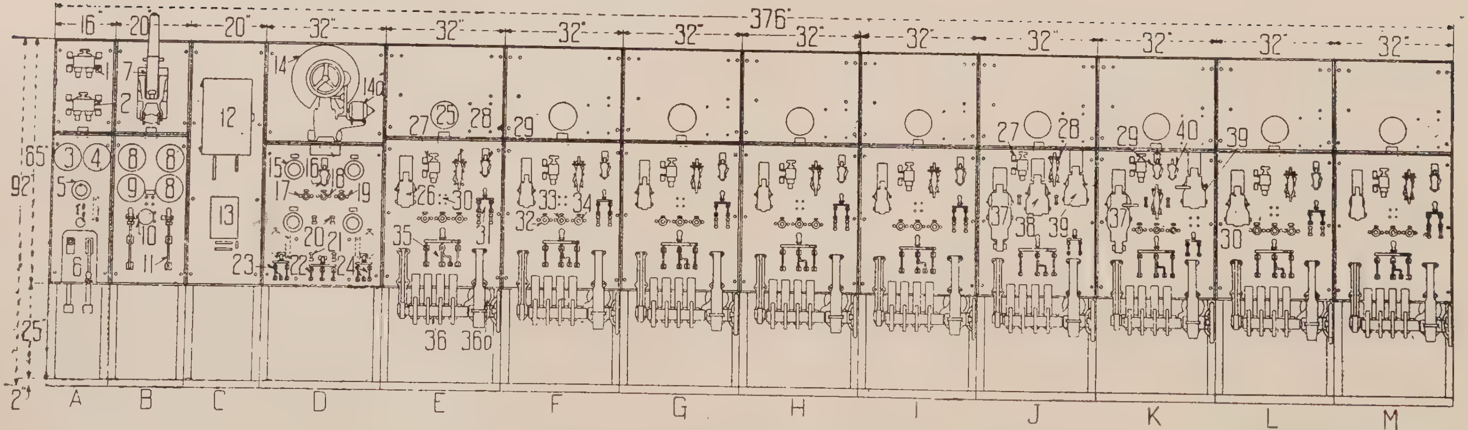
(1) An individual direct-current motor for driving each section of the machine. The close speed regulation of the d-c. motor and the wide range of speed adjustment by both field and voltage control make this the most suitable type of motor for this application.

(2) A separate generator for driving the complete paper machine. The voltage of this generator can be varied to change the speed of the entire machine. This gives a very effective and simple method of speed change for the machine as a whole. This generator is driven either by a synchronous motor or by a steam turbine, depending on the primary source of power.

(3) An exciter, giving a constant source of direct current, is required to furnish power to the generator and motor fields. The same power is also used for operating the control equipment. The exciter may be driven either from the generator shaft or from a separate unit.

(4) Synchronous Motor Panel, Fig. 316, Panel A. This is required for the synchronous motor, when one is used. This control panel consists of a circuit breaker for overload protection, the necessary instruments and means for starting the synchronous motor. Details of synchronous motor starters will be found in another chapter.

TYPICAL CONTROL BOARD
SECTIONAL PAPER MACHINE DRIVE
OUTLINE DIMENSIONS IN INCHES



A. Synchronous Motor Panel
B. D-C. Generator Panel.
C. Voltage Regulator Panel.
D. Master Control Panel.
E. Couch Panel.
F. 1st Press Panel.
G. 2nd Press Panel.
H. 3rd Press Panel.
I. 4th Press Panel.
J. 1st Dryer Panel.
K. 2nd Dryer Panel.
L. Calender Panel.
M. Reel Panel.
1. Overload relay for blower motor.
2. Overload relay for exciter motor.
3. Synchronous motor ammeter.
4. Synchronous motor field ammeter.
5. Synchronous motor rheostat.
6. Synchronous motor oil starting switch (automatic).
7. Carbon circuit-breaker for D-C. generator.
8. Ammeters for generator and exciters.
9. Voltmeter for generator, exciters and motors.
10. Voltmeter receptacles.
11. Generator knife switches.
12. Voltage regulator.
13. Voltage regulator.
14. Motor operated generator rheostat.
14*a*. Pilot Motor for item 14.
15. Hand rheostats.
16. Master control relay.
17. Push button (Fast)
18. Push button (Stop)
19. Push button (Slow)
20. Control circuit fuses.
21. Motor fuses (Master rotary contactor)
22. Knife switch (Master rotary contactor)
23. Exciter knife switch.
24. Exciter knife switch.
25. Section motor ammeter.
26. Line contactor.
27. Overload relay.
28. Low voltage relay.
29. Full field relay.
30. Voltmeter receptacle.
31. Section Control knife switch and fuses.
32. Push button (Stop).
33. Push button (Start).
34. Push button ("Jog").
35. Section motor knife switch.
36. Section motor cam accelerating switches (motor operated).
36*a*. Pilot motor for item 36.
37. Line contactor.
38. Series contactor.
39. Parallel contactor.
40. Pilot motor relay.

FIG. 316

(5) Generator Control Panel, Fig. 316, Panel B, C, and D. A motor-operated field rheostat is mounted on this panel for changing the generator field from one or more push-button stations. This in turn adjusts the speed of the paper machine. Switching means should be provided for connecting the generator to the circuits feeding the motors, also any instruments that may be desired.

(6) Control Panel for Each Sectional Drive Motor, Fig. 316, Panels E, F, etc. Each panel consists of an automatic starter for the motor and a hand-operated field rheostat. At times it is necessary to start and stop an individual section without disturbing the other parts of the machine. This can be easily done by means of the automatic starter which is usually provided with push-button control. After the motor has been brought up to speed it may be necessary to adjust the field with the hand-operated rheostat in order to bring the speed within the range of the regulating device.

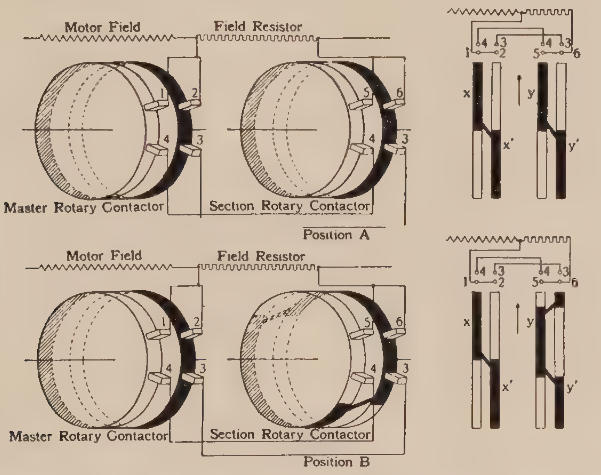


FIG. 317. Schematic Diagram and Development of Master and Section Rotary Contactors

(7) Automatic Regulating Device, Fig. 317. This is a device for maintaining the speed of each sectional motor in its proper relation to the other motors. The regulation is accomplished by adjusting each section to a common speed known as the master speed or master regulator; details of this regulator will be discussed later.

Position A shows the master rotary contactor and the section rotary contactor in the same phase relation. In this position, with the rotation in the direction indicated and the speed of both remaining constant, the field resistance will be cut out all of the time. For a clearer understanding of this refer to the development at the right. As segments x and y close the terminals *4–1* and *4–5* the field resistance is totally short-circuited. Then as these terminals are opened, terminals *3–2* and *3–6* are closed by segments x' and y', and again the field resistance is short-circuited. This means that for an entire revolution of the contactors, the field resistance remains short-circuited, and will continue so until the section contactor changes its position with respect to the master contactor. Position B shows the section rotary contactor lagging behind the master rotary contactor by an angular displacement of 45 degrees at constant speed which, following the same line of reasoning as before, causes the field resistance to be cut out three-quarters of the time per revolution. Referring to the development, as segment x closes terminals *4–1*, segment y' closes terminals *3–6*, and the circuit remains open, leaving all the resistance cut in. However, after one-eighth of a revolution, segment y closes terminals *4–5* and segment y opens terminals *3–6*.

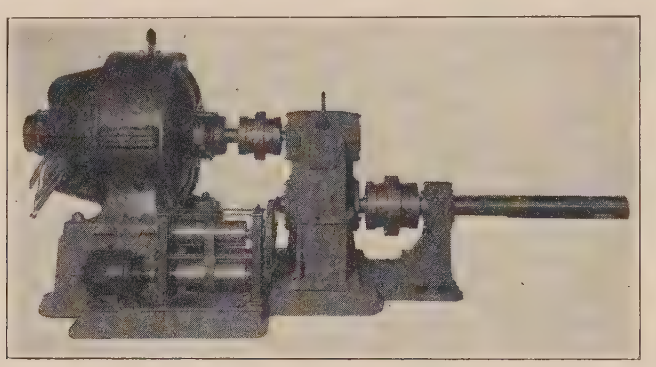


FIG. 318. Section Motor, Speed Changer and Section Rotary Contactor

This closes the circuit and the resistance remains short-circuited for three-eighths of a revolution, at which place segment x opens terminals *4–1* and segment x' closes terminals *3–2*. This once more leaves the resistance cut in until one-eighth of a revolution has been made, when segment y' closes terminals *3–6* and segment y opens terminals *4–5*. The resistance is now short-circuited for three-eighths of a revolution, at which place a complete revolution has been made. In this case the field resistance is cut in one-fourth of the time for each half revolution of the contactors, or in other words, during each revolution, the resistance is cut in for two periods, each corresponding to one-eighth of a revolution each and 180 degrees apart.

(8) Means of Adjusting the Automatic Regulating Device for Each Section to Give the Proper Speed to that Section, Fig. 318. This is a rather difficult feature; the old systems of jack shaft drive used large cone pulleys to drive each section, the speed being changed by shifting a belt across the face of the pulleys. When individual motors are used to drive a section, the speed relation of the regulating device for each motor must be adjusted in order to give that particular section its desired relative speed to the other sections.

During the manufacture of paper the film of wood pulp is gradually dried and ironed out into a compact hard sheet of paper. As the paper passes through the various sections of the machine in the course of manufacture, it is stretched, therefore, the dry end of a paper machine must run faster than the wet end. Since each section is mechanically separate from every other section the speed of each motor can be adjusted to give the proper speed or "draw" of the paper. The automatic regulating device must maintain this "draw" at a constant value, otherwise paper will accumulate between sections and be ruined or the paper will be torn apart; this means that the regulation must be absolute and not approximate.

The automatic regulating devices so far developed may be grouped under three general headings:

(1) Synchronous motor regulation.
(2) Field rheostats of the step type.
(3) Field rheostats of the intermittent type.

SYNCHRONOUS MOTOR REGULATION

If a synchronous machine is connected to each section and the a-c. windings of these machines are connected together through bus bars it can be readily seen that when the speed of each synchronous machine is adjusted so that its frequency is in synchronism with the master frequency, the tendency will be for each machine to hold its particular section in synchronism. If a particular section tends to run slow its synchronous machine will act as a motor supplying the necessary power to maintain the synchronous speed. If a section tends to operate fast the synchronous machine will become a generator supplying power to the common bus and loading up this section so as to hold it down to synchronous speed if the machine is large enough to supply the necessary power for maintaining constant speed. This system requires the synchronous machines to be from 20 to 25 per cent of the rating of the d-c. motor driving the section to which the machine is attached.

The important problem in the use of this system is the mechanical means for adjusting the speed of the synchronous machines to a common frequency for different section speeds. One method of accomplishing this is to use cone pulleys; this is subject to belt slippage which was one of the difficulties experienced with the jack shaft drive formally used. Since the power transmitted, however, is only 25 per cent of that necessary to drive each section the load on the cone pulleys was proportionally smaller and the difficulty due to belt slippage was reduced.

Another means of synchronizing consists in making both elements of the synchronous machine rotate. One element was geared directly to the paper machine and the other element operated by a small motor. The problem now becomes one of maintaining the small motor at a constant speed; this can be done in various ways so that a regulator of the synchronous motor type may be successful on moderate speed paper machines. The accuracy of regulation becomes of more importance as the speed of the paper machine increases.

Field Rheostats of the Step Type

By this is meant a field rheostat of the ordinary type having a series of contacts mounted in a circle and an arm moved across these contacts to change the strength of the d-c. motor field. Two systems using this form of regulation have been placed in successful operation.

One system uses a jack shaft to provide the master speed for regulation. Each section of the machine is provided with a set of differential gears for operating the field rheostat controlling its driving motor. One element of the differential gearing is connected to the jack shaft, the other element is connected to the paper machine section through a small pair of cone pulleys. When the speed of the section is at the proper value the cone pulleys are adjusted so that the speeds of both elements of the differential gearing are the same and the field rheostat contact arm remains stationary. If a section tends to increase or decrease in speed the differential gearing changes the field rheostat arm in the proper direction to bring the motor back to its proper speed.

Care must be exercised in designing a system of this kind to prevent an overtraveling of the rheostat arm which would cause "hunting" or oscillation in the speed.

Another system of this type of control uses a motor-operated field rheostat controlled by a relay. The relay responds to a difference in frequency of two alternating-current circuits. To understand this principle let us consider a wound secondary induction motor. When the primary is connected to a source of alternating current and the secondary circuit is closed through a resistor the motor rotates due to the primary rotating field inducing a current in the secondary. If instead of connecting the secondary to a resistor, we connect it to a source of alternating current of the proper frequency to cause a rotating field in the secondary of the same speed as the rotating field caused in the primary, the motor will not rotate, as there will be no difference in frequency to exert a rotating torque. If the frequency in the secondary is increased or decreased, the motor will tend to rotate in either a positive or negative direction depending on the relation of the secondary to the primary frequency. It is interesting to make this experiment with a wound secondary motor. A very small change in secondary frequency will cause the motor to rotate at a very slow speed but with considerable torque. The method is very accurate and the motor responds promptly to such a change. A motor of this type is used as a relay, the primary being connected to a common source of alternating current which serves as the master frequency. The secondary is connected to a frequency changer driven by the section to be regulated. This frequency changer is connected to the section drive through cone pulleys so that its frequency can be adjusted to give no rotation in the relay when the section is operating at the desired speed. Any change in the speed of the section alters the frequency supplied to the relay and causes it to rotate in the proper direction to change the field rheostat so that the section motor is brought back to normal speed.

The movement of the field rheostat is made intermittent and consists of a series of impulses with a time interval between. These impulses allow the section motor to respond to each change in its field rheostat before another change is made; in this way the field rheostat does not overtravel to cause "hunting" or an oscillating speed.

The master frequency is changed when the speed of the entire paper machine is changed so that the adjustment between sections will remain constant without further adjustment.

This method of control is a little sluggish in functioning and requires considerable apparatus.

Field Rheostat of the Intermittent Type

This type consists of a resistor in series with the motor field which is rapidly cut in and out of circuit. The entire resistor or only a portion of it may be short-circuited at any instant. The principle is the same as that used for voltage regulators for large generators. The resultant effect on the motor field is dependent on the percentage of time the resistor is short-circuited. This percentage may be changed in small increments which makes the regulator the equivalent of a rheostat with an infinite number of steps, it also gives a quick change in field strength.

A simple explanation of this scheme can be obtained by assuming that two brushes are in contact with a portion of a rotating metal cylinder; this can be visualized by assuming a cylinder of insulating material mounted on the shaft of a small motor. On the surface of this insulating material is a circular copper plate covering a portion of the circumference only. The two brushes engaging this copper plate are connected across the terminals of a resistor in series with the field of the motor to be regulated. When the cylinder is rotated the brushes will short-circuit the resistor a portion of the time so that the resultant field current will be somewhere between that obtained with the resistor entirely short-circuited and that obtained with the resistor entirely in circuit. The periods of open and closed circuits are so short that the flux in the motor field will not vary, on account of the inductive lag in the circuit.

If we assume means for quickly changing the percentage of circumference covered by the metal strip we would then have a device that would give us different field currents, depending upon the percentage of the revolution during which the brushes are short-circuited. A device of this kind is not practicable in itself but the same results can be obtained by using two cylinders with two sets of brushes in parallel (Fig. 317).

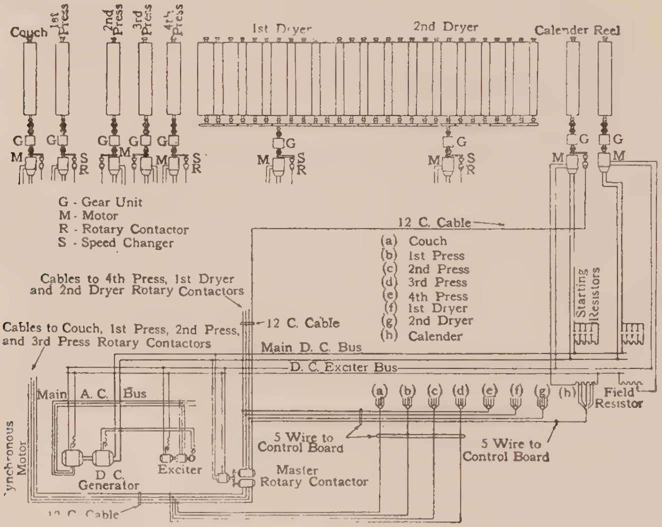


Fig. 319. Schematic Diagram of Sectional Motor Drive and Control

One of these cylinders can be shifted in its position relative to the other so that the brushes will short-circuit the resistance for different percentages of time. Automatic means can be provided for shifting the relative position of the two cylinders so as to vary the motor speed.

This method can be used to control the relative speeds of the sectional drive motors. One commutator for each machine is mounted on a common shaft and driven by one section of the paper machine or by independent means; this constitutes the master regulator or commutator. In parallel with each of these master commutators are connected individual commutators, one of which is driven from each section of the paper machine through a set of cone pulleys. The speed of each of these sectional commutators can be adjusted by means of the cone pulley to give the motor driving that section its proper relative speed. Any change in this motor speed will shift the relation between the section commutator and the master commutator so as to change the strength of the motor field in the proper direction to return it to its normal speed. This system is illustrated diagrammatically in Fig. 317, which shows one master commutator and one sectional commutator. The master commutators may all be mounted together and driven from a common source or each master commutator may be located adjacent to the section it controls and driven by a small synchronous motor connected to a master frequency.

A further modification of this method of control consists in using a single commutator, bearing a complete ring of copper; one edge of this copper band is tapered so that different widths of the surface are covered at different points of the circumference distances. A development of this copper strip looks like a wedge and is illustrated in Fig. 321. This commutator is mounted on the shaft of a synchronous motor driven from a master frequency and has an internal thread like a nut. A shaft having a screw thread extends inside of the commutator and is driven from cone pulleys connected to the section to be regulated. The speed of the screw shaft can then be adjusted so that it is the same as the speed of the synchronous motor. Under these conditions there will be no relative motion between the screw and the nut. If, however, the sectional speed changes, the commutator will be shifted, in an axial direction. In contact with this tapered ring or commutator is a series of brushes; each brush short-circuiting a section of the resistor in series with the motor field, as illustrated in Fig. 321. The difference in speed of the section and the synchronous motor causes this commutator to

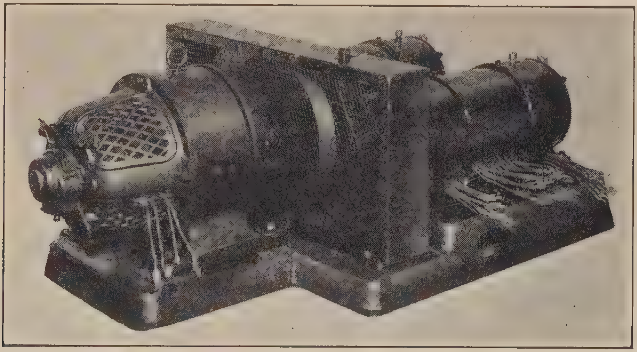


Fig. 320. Master Rotary Contactor

move in the proper direction to change the field strength of the section motor to bring it back to its proper relative speed. The advantage of this last method is the ability to use a large number of brushes and to change only a portion of the resistor at any one time. This materially reduces the arcing. For heavy motor currents parallel sections of resistors could be used and one section at a time short-circuited thus subdividing the current handled.

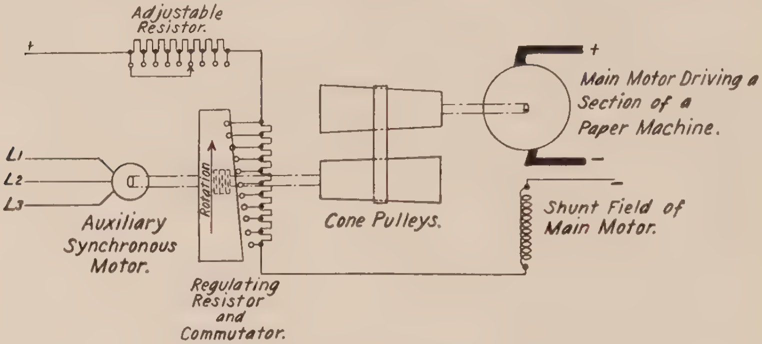

Adjustable Resistor.
+
L1
L2
L3
Auxiliary Synchronous Motor.
Rotation
Regulating Resistor and Commutator.
Cone Pulleys.
+
Main Motor Driving a Section of a Paper Machine.
−
−
Shunt Field of Main Motor.

FIG. 321. Diagram for Rotary Contactor

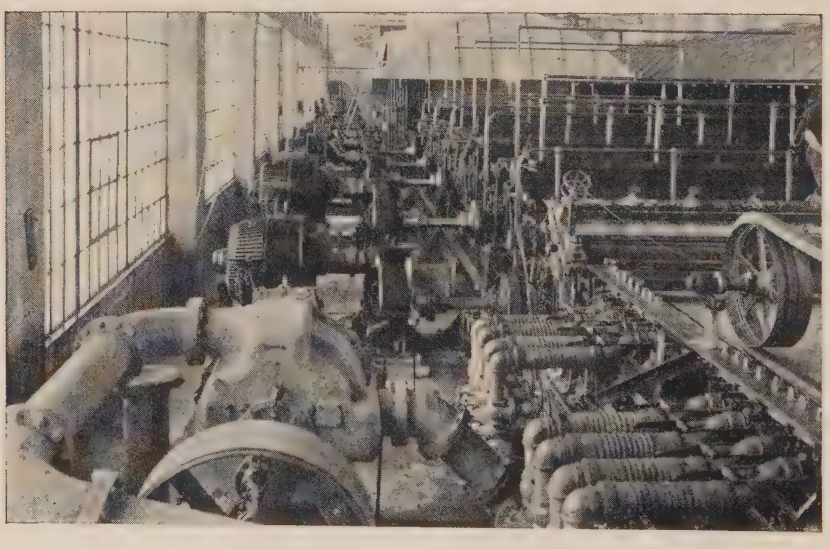


FIG. 322. Wet End of Paper Machine Showing Couch and Press Sections

In the description just given no attempt has been made to furnish a complete wiring diagram for a sectional paper machine drive as such a diagram would appear very complicated and would serve no useful purpose. The illustration of the control panels indicate the extent of the control apparatus and gives a good general idea of the equipment used.

Every complicated controller of this kind can be subdivided into its elements (Fig. 316), as given earlier in this chapter. The diagrams are then made up for each element and then combined in a complete diagram. In analyzing a complicated diagram of this kind it should first be subdivided into its elements. This will materially simplify an understanding of the whole scheme. In many cases a portion of the diagram repeats itself. In this application the control panel for each section motor is practically the same. This means that there are from 8 to 12 portions of the diagram which are repetitions of each other, illustrating how seemingly complicated diagrams can be simplified by a preliminary analysis.

Complete diagrams of this kind are seldom alike as each installation usually embodies special features, but the underlying principles remain the same and should be thoroughly mastered before attempting to understand the complete diagram.

SUMMARY OF CHAPTER XXVIII

Cylinder Paper Machine: In the cylinder type of paper machine the stock is fed upon a rotating cylinder, the coating thus formed being deposited on a moving felt. Other cylinders may deposit additional coatings until a sheet of the desired number of layers or thickness is built up.

Fourdrinier Paper Machine: In the Fourdrinier type of paper machine the stock is fed upon a wide moving brass wire belt or screen (Fourdrinier wire), at the driven end or breast roll, the flat sheet thus formed leaving the wire at the driving end or couch roll, and passing through the presses, dryers, and calenders, to the reel. Part of the water in the stock falls through the meshes of the Fourdrinier wire, more is extracted by vacuum boxes over which the wire slides, and still more is pressed out between the press rolls. The sheet is dried around the steam heated dryer rolls, a finish is imparted to it by the calender rolls, and it is wound by the reel.

Drives: The sections of the paper machine may be coupled to a common line shaft, driven by a steam engine (steam drive) or electric motor (single motor drive), or they may be operated by individual motors (sectional drive). In the sectional drive the motors are supplied from a common generator, the voltage of which is varied to alter the speed of the entire machine. The generator is steam driven or, preferably, is driven by a synchronous motor. The control board comprises a synchronous motor starting panel (unless the generator is steam driven), master control panel, generator control panel, and a control panel for each section motor.

Since the sheet of paper stretches in passing through the machine each succeeding section must run slightly faster than the preceding one. Inasmuch as the extent to which the sheet stretches is variable, a speed changer, or means of adjusting the speed (or draw) of each section from time to time, independently of the others, is therefore necessary. Since the speed of a section, when once set, must not vary, an automatic regulating device is provided for each section, all of which are held in synchronism by their operation in conjunction with a master regulator.

Automatic Regulators: Three types of automatic regulating devices may be considered, as follows:

(1) Synchronous Motor Type: (a) In addition to the regular motor driving each section a smaller synchronous motor (rating 20 to 25 per cent of the larger) is coupled to each section. If any section tends to fall out of step the synchronous motor speeds it up or holds it back. The draw is adjusted by means of cone pulleys through which also the power of the synchronous motor is transmitted; hence, belt slippage may result.

(b) In another form of this regulator both elements of the synchronous motor rotate, one being geared to the machine, and the other operated by a small motor, the speed of which is kept constant in various ways.

(2) Field Rheostat, Step Type: (a) All sections are connected, through a pair of cone pulleys and differential gearing, to a jack shaft. Any difference in speed of a section causes the differential gearing to move an arm of a rheostat to cut in or out resistance, as the case may require, to bring the motor back to the proper speed. Hunting of the rheostat arm must be guarded against.

(b) The field rheostat of each sectional motor is varied as required by a small motor controlled by a relay. The relay is operated by a torque motor. The primary of the torque motor is connected to a master frequency alternating current. The secondary is connected to a frequency changer driven by the section to be regulated, which generates, as long as the section motor is at the proper speed, alternating current of the same frequency as the master frequency. Any difference in speed results in a difference in frequency, causing the torque motor to operate. Cone pulleys are provided for adjusting the draw. This method is sluggish and much apparatus is required.

(3) Field Rheostat, Intermittent Type: (a) A resistor in the section motor field circuit is rapidly cut in and out of circuit, being in the circuit part of the time and out of the circuit part of the time. The field strength tends to decrease and increase, but, owing to inductive lag, remains approximately constant. Through the operation of the regulating device the resistor is actually in circuit more or less than half of the time, according as the section motor tends to fall behind or to advance, the resultant or effective field strength being changed correspondingly.

In the regulating device (rotary contactor or commutator) stationary brushes and copper segments mounted on a rotating cylinder make contact during part of the revolution of the cylinder, the contact being broken during the other part. Two such devices are connected in series across the resistor, one (the section rotary contactor) being operated by the section motor, the other forming a portion of a master rotary contactor.

If the periods of contact of the brushes and segments of master and section rotary contactors exactly coincide, the resistor is continuously short-circuited; if the master and section contactors are one-half revolution out of phase with each other the resistor is not short-circuited; the actual condition in service approaches a mean between these two limits.

Cone pulleys are inserted in the gearing between the rotary contactors and the machine sections, to permit adjustment of the draw.

(b) In a modification of the previous scheme a commutator bearing a tapered ring of copper (resembling, if unrolled or developed, a wedge-shaped copper strip) is mounted on the shaft of a synchronous motor, threaded internally (like a nut) to receive a threaded shaft or screw driven by cone pulleys connected to the section to be regulated. The tapered ring makes contact with a series of brushes connected to resistance in the section motor field circuit. Under conditions of synchronism there is no relative motion between the screw and the nut; otherwise, the difference in speed causes a screw motion resulting in a shifting of the commutator in the proper direction to short-circuit more or less resistance, as may be required to bring the motor back to speed. An advantage of this method is that more brushes may be used and only one portion of the resistor changed at a time, reducing arcing.

CHAPTER XXIX

STEEL MILL AUXILIARIES

Steel mill drives, two classes—main drive—auxiliary drive—severity of service—four classes of control for auxiliary drives—overload and low voltage protection—two high reversing mill—three high (plate) mill—how few accelerating points?—equipment must be rugged.

The application of electric motors and controllers to steel mills naturally divides itself into two classes; namely, the main drive and auxiliary drives.

The main drive consists of large motors which may be reversing or non-reversing, depending upon the character of the mill. A great deal has been written on the subject of this main drive, as for example articles appearing in the proceedings of the A. I. E. E., Association of Iron and Steel Electrical Engineers and the *Electric Journal*. The reversing drive presents more difficulties than the continuous mill. A very interesting description of the reversing drive is given in an article on the subject of "Electric Drive for Reversing Rolling Mills," by Messrs. Sykes and Hall in the *Proceedings* of the A. I. E. E. for June, 1916.

The floor controllers for auxiliary drives comprise a large number of applications on which there are very little published data. It is hoped that the Association of Iron and Steel Electrical Engineers, together with the Steel Mill Committee of the A. I. E. E., will make a study of this problem and standardize this equipment as far as it is practical to do so. So far, the practice is uniform only in a general way, individual engineers trying out their respective ideas and profiting by their own experience and the data obtained from other mills. The d-c. series motor is still extensively used, but recently there has been strong tendency toward using a compound motor which has a limited maximum speed and assists in reducing the commutator trouble.

Few applications of electric motors and controllers involve more severe service than floor controllers used in steel mills. The motors are started and stopped very frequently, usually under heavy loads, and large starting currents are used to *obtain quick* acceleration. The control apparatus must be rugged and should have a minimum number of interlocks and other auxiliary contacts. Provision should be made for repairs and renewals in the minimum length of time. It is very desirable to have the parts subject to wear or accident removable from the front of the control board, and one man should be able to handle this work without assistance, except where the parts are very heavy.

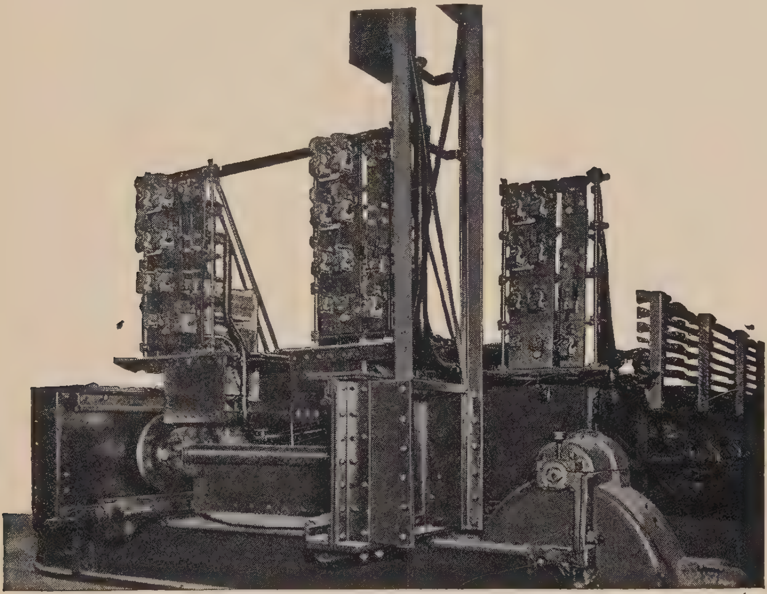


FIG. 323. Charging Machine

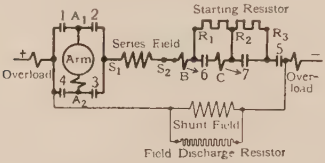
The illustration shows one end of a modern charging machine with control equipment of the magnetic contactor type

Floor controllers group themselves into four general classes for reversible service. Where a non-reversing controller is used, it follows the same grouping except that one set of reverse switches is omitted:

AA. Plugging on the reverse, without speed control;
BB. Plugging on the reverse with speed control; acceleration by shunt switches with current limit relays.
CC. Dynamic brake without speed control.
DD. Dynamic brake with speed control; the acceleration is by shunt switches with current limit relays.

Schematic diagrams showing the reversible controllers are illustrated in Figs. 324 and 325. All of these controllers consist essentially of two double pole line switches, one for forward and the other for the reverse direction of operation. The controllers illustrated use a mechanical interlock so that both forward and reverse switches cannot be closed at the same time. These switches for controllers *CC* and *DD* are provided with back contacts; when both direction switches are opened, the two back contacts complete the dynamic brake circuit. The coils maintaining pressure on these back contacts are in series with the contacts and hold them closed as long as current is flowing through this circuit. This arrangement also prevents the motor from being operated in the reverse direction as long as the dynamic brake current lasts. The single-pole contactor with blowout, which is used for opening the negative side of the line, is shown in the top row, Fig. 328 and 329. At the bottom of the panels are two contactors for short-circuiting the starting resistor. In Fig. 328, these contactors are wound with series coils and operated on the lockout principle. In Fig. 329, the contactors have shunt coils and are controlled by current limit relays. One of these relays is shown mounted underneath the resistor switch. The other relay is mounted under the direction switch.

SCHEME OF MAIN CONNECTIONS

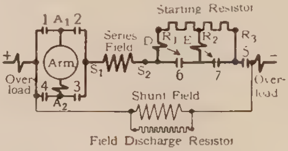


SEQUENCE OF CONTACTORS

Con	← For.			Off	→ Rev.		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○	○		○	○	○
6	○	○				○	○
7	○						○

FIG. 324

SCHEME OF MAIN CONNECTIONS



SEQUENCE OF CONTACTORS

Con	← For.			Off	→ Rev.		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○	○		○	○	○
6	○	○				○	○
7	○						○

FIG. 325

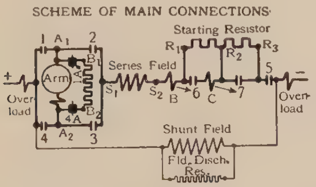
FIG. 324. Scheme of Main Connections for Form *AA* Controller

Acceleration is by means of series lockout magnet switches *6* and *7*, which are operated by series coils *B* and *C* respectively. The motor is connected for forward or reverse operation by closing contactors *1* and *3* or *2* and *4* respectively. With this form of controller, acceleration is entirely automatic

FIG. 325. Scheme of Main Connections for Form *BB* Controller

The operation of this form of controller is the same as the *AA*, except that the automatic acceleration is by means of series relays, the switches being closed by shunt coils which are in series both with the master controller and with the series relay contacts. With this scheme, acceleration is automatic up to the position at which the master controller is set. Coils *D* and *E* are the series coils of the relays which control the operation of switches *6* and *7* respectively

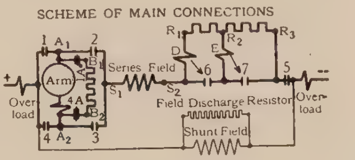
These panels have a two-pole overload relay and a low-voltage protective relay. The overload relay is provided with two coils, each having a dashpot time-limit device. The plungers actuated by either of these coils engage a single switch member, which opens the potential relay circuit in case of overload. The use of the two-pole overload relay and the negative line switch gives maximum protection against grounds, which are apt to occur in applications of this kind. In the off position, the controller disconnects the armature from the line. If no negative line switch is used, one end of the series field is connected to the line, so that it is not safe to work on the motor without opening the knife switch.



SEQUENCE OF CONTACTORS

Con	← For.			Off	Rev. →		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○	○		○	○	○
6	○	○				○	○
7	○						○
1A				○	○	○	○
4A	○	○	○	○			

FIG. 326



SEQUENCE OF CONTACTORS

Con	← For.			Off	Rev. →		
1	○	○	○				
2					○	○	○
3	○	○	○				
4					○	○	○
5	○	○	○		○	○	○
6	○	○				○	○
7	○						○
1A				○	○	○	○
4A	○	○	○	○			

FIG. 327

FIG. 326. Scheme of Main Connections for Form *CC* Controller

This controller is the same as that shown in Fig. 324, except that it is arranged for dynamic braking in the off position of the contactors. The brake resistor B_1 B_2 is connected across the motor armature through contacts *1A* and *4A*. These contacts are on the bottom of switches *1* and *4* so that both sets of reverse switches must be open before dynamic braking is obtained. The current in passing through contacts *1A* and *4A* energizes magnets which press these contacts firmly together as long as the dynamic brake current is flowing, and effectually prevent the reversal of the motor as long as its speed is sufficient to send current through these coils

FIG. 327. Scheme of Main Connections for Form *DD* Controller

This controller is the same as that shown in Fig. 325, except that dynamic braking is provided in the off position in the same manner as shown in Fig. 326

In the upper right hand corner of the panel is a two-pole, single-throw knife switch for disconnecting the feed wires from the panel. A similar two-pole single-throw knife switch and fuses are located underneath the overload relay for the control wiring. The main line knife switch, as well as the smaller knife switch and fuses, can be provided with sheet metal covers to protect the operator from accidental flashes if the switch is opened under load. The large knife switch is provided with an attachment for a padlock so that the switch can be locked in the open position when repair work is going on. By opening the main knife switch and closing the control knife switch, the control circuits can be tested out and the operation of the contactors observed, to see that the equipment is in working order, before power is applied to the main contacts.

Usually these control panels are protected by grill work or in some other manner, or they are mounted in a gallery, which is accessible only to authorized persons. In some states these precautions are required by law. In the main, however, the steel mill companies recognize the importance of such safety provisions and use them whether required by law or not.

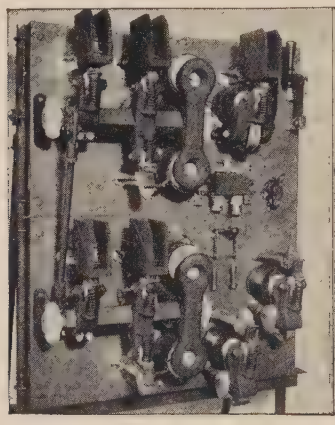


FIG. 328

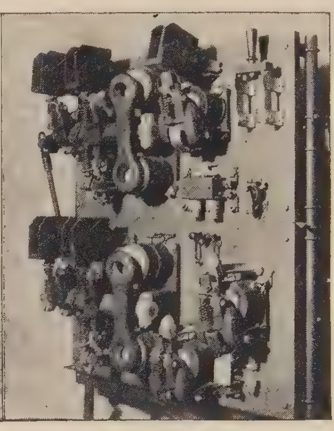


FIG. 329

FIG. 328. Form *CC* Controller

This controller corresponds to the diagram shown in Fig. 326. The reverse switches have two top contacts, *1* and *3* for forward operation with back contact *1A*, and *2* and *4* for reverse operation with bottom contact *4A*. These switches are mechanically interlocked by the rod at the left, to prevent both from closing at the same time. Contact *5* is shown in the upper right hand corner, and lockout accelerating switches *6* and *7* at the bottom of the panel. Both the reverse switches and the line contactor *5* are actuated by shunt coils not shown in the diagram. An overload relay is located directly under switch *5* and two-pole knife switches are provided for disconnecting the main and control circuits from the line

FIG. 329. Form *DD* Controller

This controller corresponds to the diagram shown in Fig. 327. It is the same as Fig. 328, except that accelerating switches *6* and *7* are actuated by shunt coils which are controlled by the series relays, one of which is shown mounted underneath switch *6*

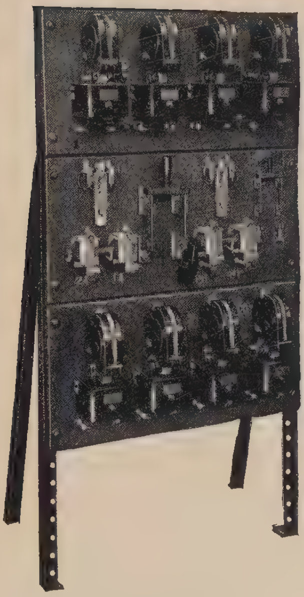


FIG. 330

FIG. 331

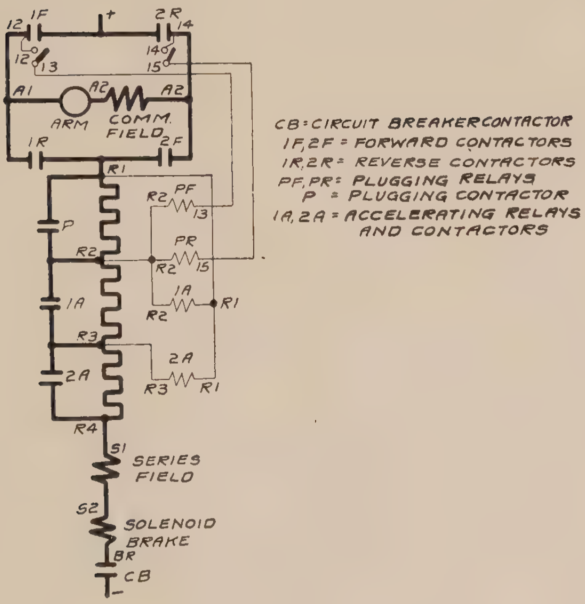
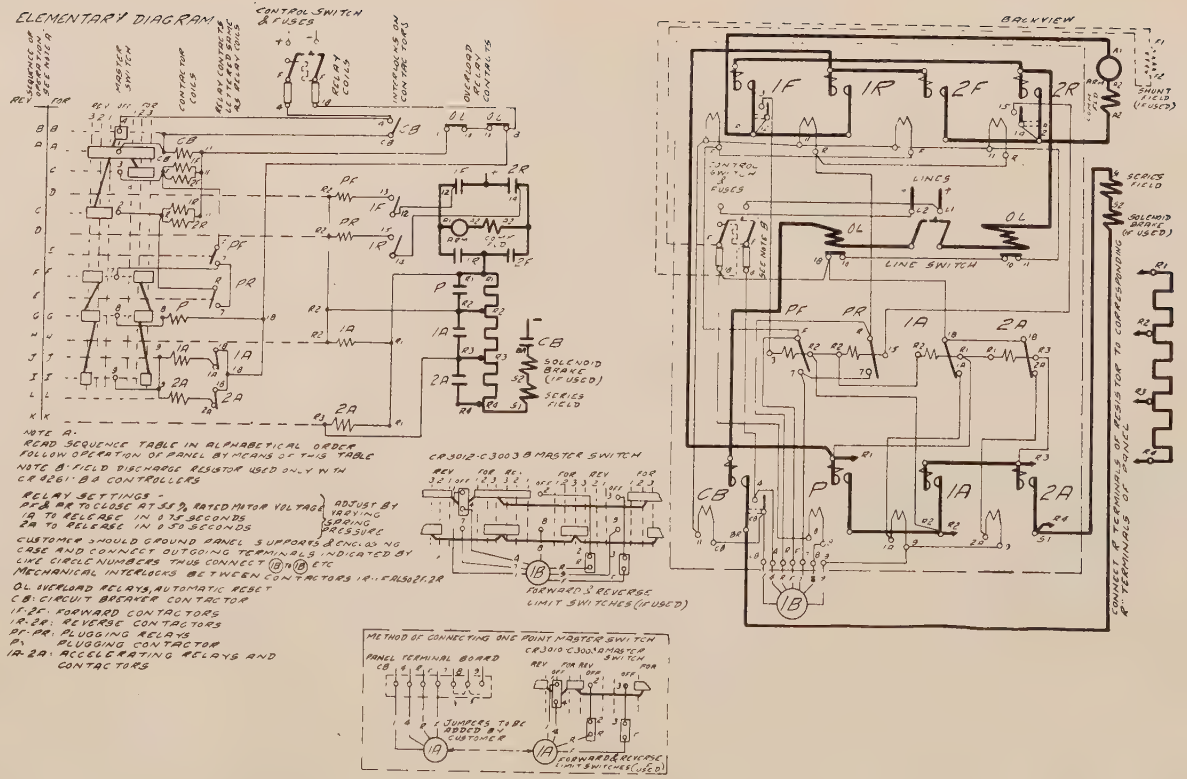


FIG. 332

FIGS. 330, 331 and 332. Steel Mill Controller, Plugging Reverse


ELEMENTARY DIAGRAM
SEQUENCE OF OPERATION SEE NOTE A
REV
FOR
MASTER SWITCH
CONTACTOR COILS
RELAY CONTACTS LETTERED SAME AS RELAY COILS
CONTROL SWITCH & FUSES
RELAY COILS
INTERLOCKS ON CONTACTORS
OVERLOAD RELAY CONTACTS
CB
OL
1F
1R
2F
2R
PF
PR
P
1A
2A
ARM
COMM FLD
SOLENOID BRAKE (IF USED)
SERIES FIELD
CR3012-C3003B MASTER SWITCH
FORWARD & REVERSE LIMIT SWITCHES (IF USED)
METHOD OF CONNECTING ONE POINT MASTER SWITCH
CR3010-C3003A MASTER SWITCH
PANEL TERMINAL BOARD
JUMPERS TO BE ADDED BY CUSTOMER
FORWARD & REVERSE LIMIT SWITCHES (IF USED)
BACKVIEW
SHUNT FIELD (IF USED)
CONTROL SWITCH & FUSES
SEE NOTE B
LINES
LINE SWITCH
CONNECT R TERMINALS OF RESISTOR TO CORRESPONDING R TERMINALS OF PANEL
R1
R2
R3
R4
1B

NOTE A·
READ SEQUENCE TABLE IN ALPHABETICAL ORDER
FOLLOW OPERATION OF PANEL BY MEANS OF THIS TABLE

NOTE B· FIELD DISCHARGE RESISTOR USED ONLY WITH CR4261·B4 CONTROLLERS

RELAY SETTINGS -
PF & PR TO CLOSE AT 55% RATED MOTOR VOLTAGE
1A TO RELEASE IN 0.75 SECONDS
2A TO RELEASE IN 0.50 SECONDS
ADJUST BY VARYING SPRING PRESSURE

CUSTOMER SHOULD GROUND PANEL SUPPORTS & ENCLOSING CASE AND CONNECT OUTGOING TERMINALS INDICATED BY LIKE CIRCLE NUMBERS THUS CONNECT (1B) TO (1B) ETC
MECHANICAL INTERLOCKS BETWEEN CONTACTORS 1R·1F ALSO 2F.2R

OL. OVERLOAD RELAYS, AUTOMATIC RESET
CB: CIRCUIT BREAKER CONTACTOR
1F-2F: FORWARD CONTACTORS
1R-2R: REVERSE CONTACTORS
PF-PR: PLUGGING RELAYS
P: PLUGGING CONTACTOR
1A-2A: ACCELERATING RELAYS AND CONTACTORS

FIG. 333. Connection of Panel with Two Accelerating Contactors and One Plugging Contactor

The reason for dividing the controllers into four classes can best be understood by giving some of the applications for each class of control.

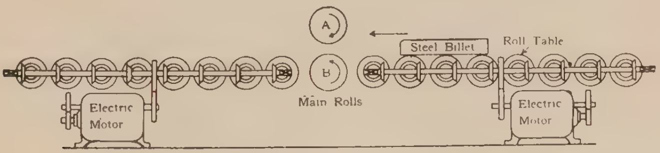
Class *AA* controllers are applied to all of the main and auxiliary tables requiring one speed only. These tables usually consist of a series of rollers; the steel rests on the rollers and is moved forward or back by revolving the rollers.

Class *BB* controllers are used for similar applications where two or more speeds of operation are required.

Class *CC* controllers are applied to screw-downs, lifting and tilting tables, manipulator fingers, and side guards.

Class *DD* controllers are used for metal mixers and Bessemer converters, and are also used for the same applications as class *CC* where speed control is desired.

The use of four controller combinations is not desirable where one or two combinations will do the work. In addition, a number of steel mill engineers object to the present lockout switch, as its operation is not reliable on light loads. It is hoped that development in the controller art will enable a single controller to be used for all applications. The dynamic brake feature need not be connected in where a series motor is used. For compound motors, the dynamic brake is preferable to plugging, as it limits the commutating requirements in the motor and the controller can be so designed that the reversing will be as quick or even quicker than where plugging is used. The more extensive use of compound-wound motors for steel mills will make the use of dynamic brake more general.



FIGS. 334. Typical Application of Electric Motors to Reversing Roll Tables of Blooming Mill

A two high reversing mill is outlined in Fig. 334. The circles *A* and *B* represent the main rolls for fabricating the steel. The horizontal row of circles represents the table rolls which are driven by electric motors through suitable gearing. The steel billet is moved up to the main rolls in the direction shown, by revolving the table rolls. After the billet has entered the main rolls, it is carried through by the action of these rolls and is delivered to the table rolls on the left hand side. By reversing the direction of the main rolls and table rolls on both sides, the billet is fed back through the main rolls, the process being repeated until the desired reduction is secured. Each of these operations is known as a "pass." After the billet has been rolled to a given size by one set of main rolls, it is often passed to other rolls, or the same set of rolls may have several different shaped grooves, so that the billet can be moved sideways and made to enter these grooves during successive passes. The movement of the billet sideways is controlled by the side guards, which consist of horizontal bars, which are moved across the table rolls for placing the billet in the proper position. When it is desired to turn the billet over, manipulator fingers are used. These fingers are attached to the side guards and extend underneath the billet between the table rolls. These manipulator fingers are connected so that they can be raised and lowered. This movement, when properly directed, serves to turn the billet over. The distance between the main rolls *A* and *B* is adjusted by means of an electric motor, geared to screws which raise the top roll. If the screws are raised, the hydraulic pressure will cause the top roll to follow. If it is desired to lower the top roll, it is necessary for the motor to drive the screws down with sufficient force to overcome the hydraulic pressure. This is known as the "screw-down" motion. It can be readily seen that the adjustment between these rolls must be very exact, and therefore it is important that the control of the screwdown motor provide for stopping this motor with practically no drift.

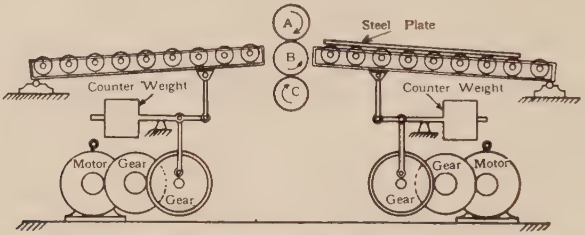


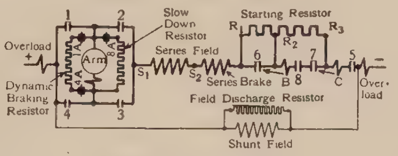
FIG. 335. Typical Application of Motors and Gears to Tilting Roll Table of Plate Mill

A three-high mill with tilting tables is shown in Fig. 335. The main rolls are illustrated by circles *A, B* and *C*. Roll *B* is an idler. The steel to be rolled in this form of mill is usually a plate and the mills used are usually called "plate mills." The red hot steel plate is passed alternately between rolls *A* and *B* from right to left and back from left to right between rolls *B* and *C*. The screw-down motion adjusts the distance between rolls *A* and *C*, roll *B* being free so that when the pass is made between rolls *A* and *B*, roll *B* is forced against roll *C*. When they pass in the opposite direction between *B* and *C*, roll *B* is pressed against *A*.

In order to pass the steel plate alternately between *A* and *B* and *B* and

C, it is necessary to tilt the tables; hence, the term "tilting table." The end of the table away from the rolls is hinged and the opposite end of the table is raised or lowered by means of an electric motor. These tables have two fixed positions, which are previously adjusted so that the motors are automatically stopped when the tables reach these positions. The tables are counter-weighted, as shown, in order to equalize the work done between raising and lowering. The masses moved, however, are great and as an accurate stop is required, it is necessary to provide a slowdown before the final stop. Fig. 336 illustrates the controller used for this purpose. When the table approaches either limit of travel, switches *7* and *8* are opened and switch *8A* is closed. This inserts the starting resistance in series with the motor and also provides a shunt around the motor armature. These connections can be adjusted to give a positive slow speed, from which an accurate stop can be made. The problem is very similar to that of an elevator or skip hoist, which is moved up and down between fixed limits. In bringing tables to rest, switches *1A* and *4A* are

SCHEME OF MAIN CONNECTIONS



SEQUENCE OF CONTACTORS

Con	For.			S.D.	Off	S.D.	Rev.		
1	○	○	○	○					
2						○	○	○	○
3	○	○	○	○					
4						○	○	○	○
5	○	○	○	○		○	○	○	○
6	○	○						○	○
7	○								○
8	○	○	○				○	○	○
1A					○	○	○	○	○
4A	○	○	○	○	○				
8A				○	○	○			

FIG. 336. Main Connections of Controller with One Point Slow-down

This controller is the same as Fig. 326 with the addition of switch *8*. When it is desired to slow down the motor, preparatory to stopping, the shunt coil of switch *8* is disconnected from the line by means of the limit-switch shown in Fig. 337. This, in turn, causes coil *B* to open *6* and therefore inserts all the starting resistance and closes a shunt around the armature through contact *8A*, leaving the motor connected to the line with the starting resistor in series with, and the slow-down resistor shunted across the armature, providing a slow running motion. The bottom contact of switch *8*, marked *8A*, has a series coil to retain the switch in the open position as long as current is flowing through contact *8A*. If the line switches were open and the dynamic resistance omitted, some dynamic brake action would occur due to the resistor across the armature through contact *8A*. This resistor, however, is of too large an ohmic value to give a quick stop, and it is, therefore, necessary to use the additional dynamic braking resistor to bring the motor quickly to a standstill closed at the same time that the line switches are opened, which provides a dynamic braking path of low resistance around the armature. In addition, the circuit through the mechanical braking magnet is opened so that the brake shoes set and assist in stopping the load, as well as hold it securely. The accurate placing of these tables at either limit of travel is facilitated by the use of a crank motion. The stop is made when the crank is at either the top or bottom of the travel, so that a slight variation in the point of stopping makes little difference in the location of the table.

The controller switches are operated automatically by a stop motion switch, shown in Fig. 337, whose actuating shaft is connected to the mechanism. On the shaft is mounted a set of cams which open or close the limit switches at the proper time. The cams are adjustable, so that each switch can be set to open and close at the proper point in the travel. The use of the cams gives a quick motion to these switches and enables an accurate setting to be obtained.

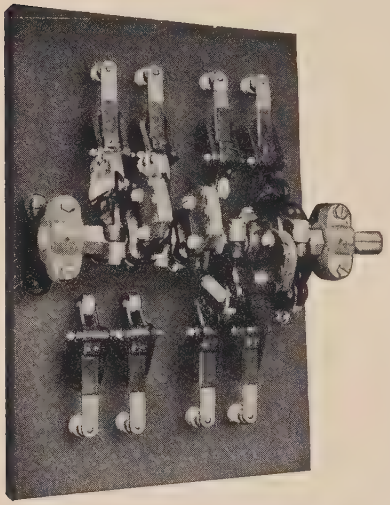


FIG. 337. Cam Limit Switch for Gear or Sprocket Connection

The motor is started by means of the master switch shown in Fig. 338. This master switch is also used in connection with the other controllers, previously described. The central position of the handle disconnects the motor from the line and resets the no-voltage switch in case the overload has opened it. The movement of the handle to either side of the center operates the controller forward or reverse. One slow-speed point and one full-speed point are provided in each direction. Where the application requires more running notches, a different form of master switch is used.

A lifting table is very similar to a tilting table, except that the table is moved vertically up and down instead of having one end hinged and the other end raised and lowered. The results accomplished are the same, but a somewhat different mechanism is used. Usually the lifting table is confined to rolling operations which do not require a very long table.

Tests indicate that, on many applications, the best results are obtained with very few accelerating points. There are two ways of approaching this problem. Those who argue for a large number of accelerating points call attention to the fact that the current can be maintained at a higher level and thus furnish a larger average accelerating torque. The advocates of a small number of steps show that each switch requires a certain time in which to operate. Where the acceleration must take place in two or three seconds, too much time is consumed in the closing of these switches; also high current peaks must be used in any event.

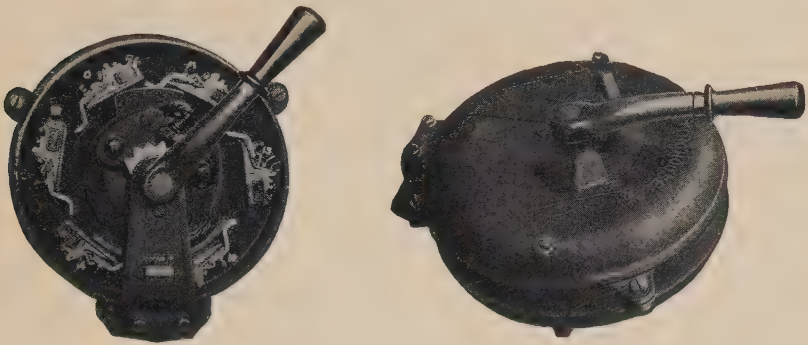


FIG. 338. Two-point Master Switch

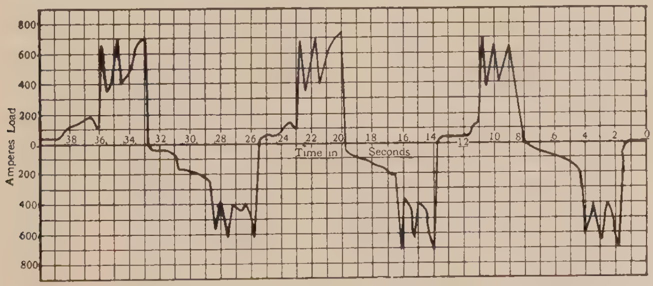


FIG. 339. Load Curve of 100-Hp., 230-Volt, Compound-wound Motor Operating Main Roll Table of a 40-Inch Blooming Mill

In Fig. 339 are illustrated tests on a 100-horsepower, 230-volt, compound-wound direct-current motor operating the main mill table for a 40-inch blooming mill. Three resistor switches were used but the tests showed that the action of the last resistor switch was too slow to be of material value. On closing the line switch, the first current peak is obtained. The second and third current peaks are caused by the first two resistor switches. The slope of the curve at each succeeding resistance point becomes steeper and steeper until it approaches a vertical line after the second resistor switch is operated. The result is that the motor has approximately reached full speed and the last resistor switch makes only a small bump in the current curve. Other tests[1] indicate that there is a reaction in the current curve, which normally tends to throw it below the calculated value of current, and then causes a secondary rise so that the wavy portion of the current curve, appearing after the second resistor switch is closed, is partly due to this effect, and still further eliminates the action of the last resistor switch. This particular application will give just as good service using only two switches for short-circuiting the resistor during acceleration. The current peaks had a maximum value of about twice full load, which is permissible for an application of this kind. The minimum value of current is a little in excess of the full-load value. This record shows an operation extending over 40 seconds and involves three starts and stops in each direction, or a total of six passes.

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[1] See Chapter X, Figs. 86 and 87.

The above application is typical of steel mill requirements for auxiliary drive. The motor is usually operated for a very short period of time, during which the period of acceleration is a large part of the complete cycle. The size of the motor is determined from the power required to accelerate the masses moved. After the motor comes up to speed, the load drops off to a very small value, as it is almost entirely friction. Motors for this service must be capable of withstanding severe mechanical shocks and must be designed to have small inertia for the torque delivered. The armatures are usually long and small in diameter, and the mechanical parts exceedingly rugged for the rating of the motor. Practice has shown that motors of standard construction, which are suitable for machine tools and ordinary machine shop applications, will be racked to pieces in steel mill service. Motors have therefore been available for a number of years, known as the "steel mill type."

Every steel mill has machine tools, fans, pumps, and other applications, which differ in no material way from similar applications in ordinary machine shop practice. Standard motors and controllers are used for these applications. It is always desirable, however, to have the contacts and interlocking parts of these controllers interchangeable with those used for floor controllers connected to the auxiliary drive, in order to reduce the spare parts to a minimum.

SUMMARY OF CHAPTER XXIX

Electric drives in steel mills may be classified as main drives and auxiliary drives. The main drive may be reversing or non-reversing. Four classes of controllers for auxiliary drives may be noted, as follows:

(*AA*) plugging on reversing, without speed control (applied to main and auxiliary tables requiring one speed only. These tables usually consist of a series of rollers; the steel rests on the rollers and is moved forward or back by revolving the rollers);

(*BB*) plugging on reversing, with speed control, acceleration by shunt switches with current limit relays (for applications similar to *AA*, where two or more speeds of operation are required);

(*CC*) dynamic braking, without speed control (applied to screw downs, lifting and tilting tables, manipulator fingers, and side guards);

(*DD*) dynamic braking, with speed control, acceleration by shunt switches, with current limit relays (used for metal mixers and bessemer converters, also for class *CC* applications where speed control is desired).

Motors and controllers in steel mills are subjected to unusually severe service, being started and stopped frequently, usually under heavy loads, and large starting currents are used to obtain quick acceleration. Interlocks and auxiliary contacts are kept at a minimum. Contactors are standardized and the parts are made easily removable, to facilitate repairs. The number of controller combinations is reduced as much as possible. Motors must withstand severe mechanical shocks and have small inertia, hence the armature is long and small in diameter, and the mechanical parts are exceedingly rugged. Motors are specially built for this service and are known as the steel mill type. There is a tendency, in order to limit the maximum speed and to reduce commutator troubles, to replace the series-wound motor with the compound-wound motor.

CHAPTER XXX

CRANES

Cranes, classification and description—traveling crane—series-wound d-c. motor best—dynamic braking—manual versus magnetic controllers—automatic retardation—protective panel—limit switch—magnetic brakes—largest pontoon crane.

CRANES of some form are used in practically every manufacturing establishment and in many other industries. They may be briefly classified as jib, gantry, traveling, tram or locomotive cranes. The function of a crane is to hoist or lower a load or move it from one position to another. Small cranes often have the hoist operated by hand. Larger cranes are operated by electric motors. These may be controlled from the floor or the operator may be located in a cage suspended from a portion of the crane structure.

The traveling crane is one of the best known types of power-operated cranes. It consists of a bridge structure provided with a truck at either end, which travels on rails lengthwise of the building. On the bridge is a pair of rails supporting a trolley which moves back and forth from one end of the bridge to the other, the hoisting mechanism being mounted on the trolley. A crane of this kind uses at least three motors, one for moving the bridge, one for moving the trolley and the third motor for hoisting the load. Some trolleys are provided with two hoists, one known as the main hoist which lifts heavy loads at relatively slow speeds, the other the auxiliary hoist arranged for lifting light loads at high speeds. Some large cranes have two trolleys each with a main and auxiliary hoist, making a total of four hoisting motors, two trolley motors and one bridge motor or seven motors in all. Direct-current series motors are considered the best for this service. They require fewer trolley wires than alternating-current motors and usually have less inertia in their rotating elements. The series direct-current motor has a very desirable speed-torque characteristic. With light loads the speeds are high and with heavy loads considerably more than normal torque can be developed, for short periods of time, at relatively slow speeds. Due to these characteristics heavy loads can be lifted when necessary, and at the same time considerable speed can be obtained in handling light loads.

Another very desirable feature of the direct-current motor is its use as a generator in lowering loads. This is known as dynamic braking and avoids the use of a friction brake for lowering the load. The heat developed by the motor may be more than when using a standard friction brake but this is more than compensated for by the reduced maintenance charge which is involved where friction brakes are used to absorb energy.

Where alternating-current power only is available induction motors of the wound secondary type may be used. The speed of these motors is controlled by inserting resistance in the secondary. A load brake must be used on the crane for lowering. This form of brake is usually arranged so that the friction load is proportional to the load on the hook. This requires the a-c. motor to do work in lowering the hook so that its speed can be controlled.

In addition to the series motors, the general purpose crane requires a controller for each motor and a limit switch and magnet brake for the hoist motors. In some cases overload protection is provided by a separate panel known as a crane protective panel. If the controller is of the magnetic type, the protective device can be included with the controller. In selecting the controller the choice lies between the manual and magnetic type. Each has its advantages and no general rule can be laid down for making a selection. The determining factors are the size of motor and the service requirements.

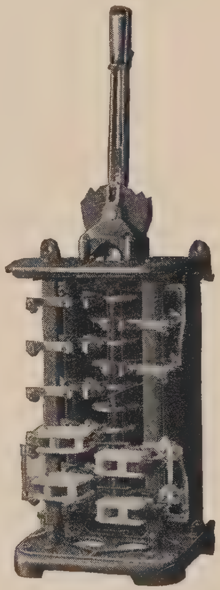


FIG. 340. Cam Type Manual Controllers

Without cover. The individual cam units are shown in Fig. 103. Each unit is operated by a cam attached to the vertical shaft. A lever-type handle is used so that the forward motion of the handle can represent lowering and the backward motion hoisting

The manual controller has a less first cost than the magnetic, the wiring connections are simpler and the total weight of the control equipment is less. On the other hand, the manual controller requires somewhat more power to operate than a master switch of the magnetic type and the contacts are less durable, as the manual operation is not as positive as the magnetic. A manual controller does not provide for automatic acceleration or deceleration. The durability of the controllers bears a direct relation to the power required to operate. If the motor is large and the service severe, the magnetic controller should be selected on account of this durability. The small manual controllers and the larger ones applied to infrequent service are satisfactory, as the additional force required

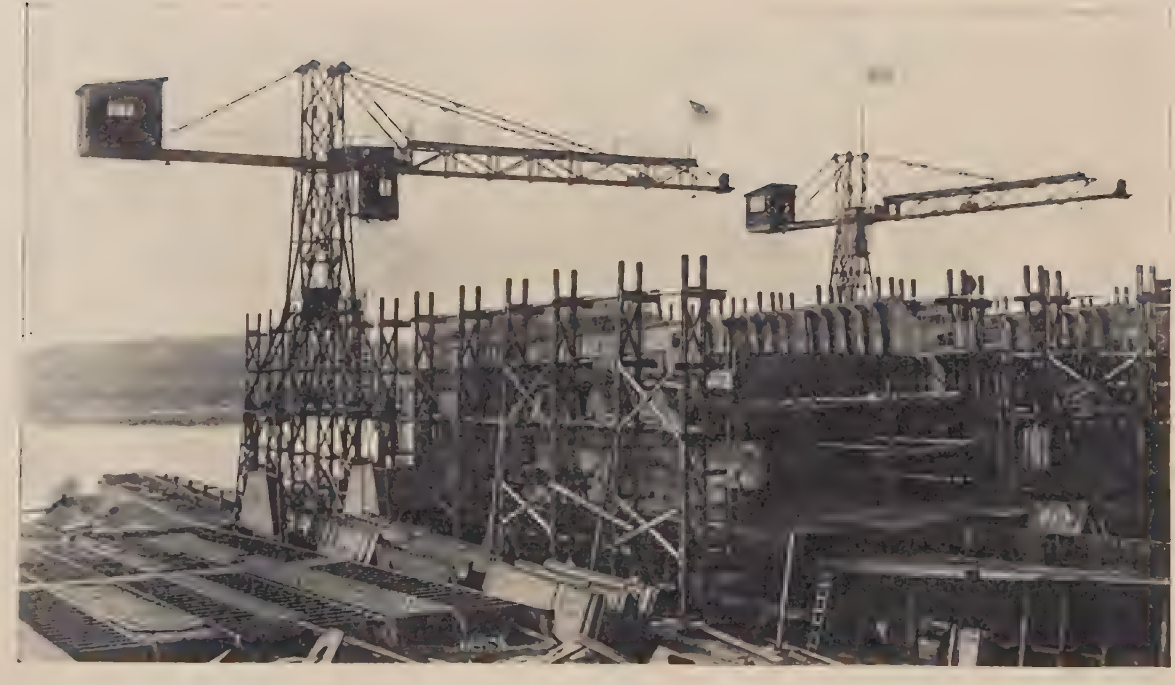


FIG. 341. Six-ton, Hammer-head Type Ship-building Crane

The crane travels on tracks and has a portal sufficiently high to span a box car. It is equipped with 20-hp hoist and crane-travel motors and 5-hp. racking and revolving motors. The crane is 58 feet from track to bottom line of boom and 80 feet from center line of portal to end of boom to move the handle is not important where the operations are infrequent.

The advantages of the magnetic type of controller consists in its durability, its ease of operation, the location of the arcing at a distance from the operator, and the small space required for the master switch, which enables the operator to observe the movements of the load more readily. This type provides automatic acceleration and deceleration, which is particularly desirable with large cranes. Where large motors are used it is desirable to have the arcing remote from the operator. The magnetic controller is heavier and occupies more space than the manual; its first cost is greater and the wiring connections are somewhat more complicated.

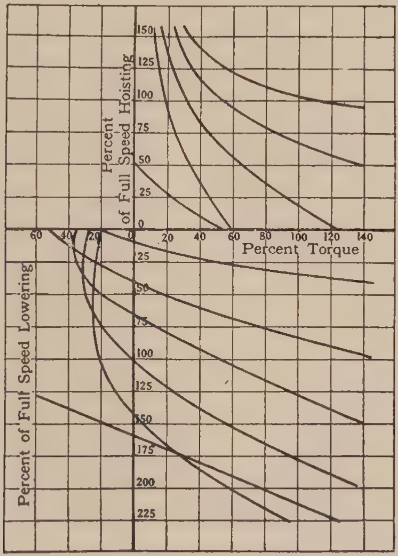
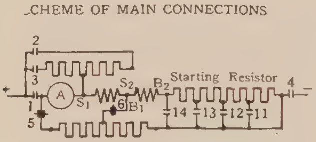


FIG. 342. Speed-torque Curve of a Series Hoisting Motor

These curves show five points hoisting and six points lowering. The curves above the zero line are for hoisting conditions and below the zero line for lowering. The lowering curves to the left of the zero line represent operation as a motor. The bottom curve, indicating a light hook requiring 20 per cent of normal load, shows that 150 per cent of normal speed can be obtained. Extensions of curves for lowering represent the motor operating as a compound-wound generator. Where a different number of notches is used, the top and bottom curves will be kept approximately as shown and the intermediate curves varied to suit the number of notches

In mills and other establishments, cranes are used for various purposes and some will have large motors and be operated very frequently, while others will be smaller and will be used less frequently. It is, therefore, logical to use magnetic controllers on some cranes and manual controllers on others. In order to make it easy for the same set of electricians to take care of these different controllers, it is desirable for them to have

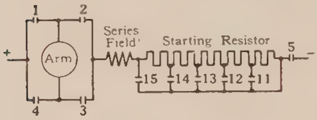


SEQUENCE OF CONTACTORS

Con	Hoist						Off	Lower					
	6	5	4	3	2	1		1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3						○							○
4	○	○	○	○	○	○		○	○	○	○	○	○
5							○	○	○	○	○	○	○
6							○						
11	○	○	○	○				○	○	○	○		
12	○	○	○					○	○	○			
13	○	○						○	○				
14	○							○					

FIG. 343. Connections for Hoist Controller

SCHEME OF MAIN CONNECTIONS

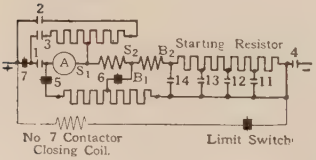


SEQUENCE OF CONTACTORS

Con	Forward						Off	Reverse					
	6	5	4	3	2	1		1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3	○	○	○	○	○	○							
4								○	○	○	○	○	○
5	○	○	○	○	○	○		○	○	○	○	○	○
11	○	○	○	○	○				○	○	○	○	○
12	○	○	○	○						○	○	○	○
13	○	○	○								○	○	○
14	○	○										○	○
15	○												○

FIG. 344. Connections for Bridge or Trolley Controller

SCHEME OF MAIN CONNECTIONS

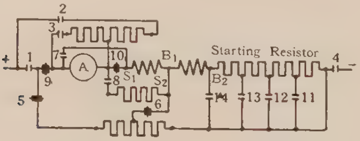


SEQUENCE OF CONTACTORS

Con	Hoist						Off	Lower					
	6	5	4	3	2	1		1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3						○							○
4	○	○	○	○	○	○		○	○	○	○	○	○
5							○	○	○	○	○	○	○
6							○						
11	○	○	○	○				○	○	○	○		
12	○	○	○					○	○	○			
13	○	○						○	○				
14	○							○					

FIG. 345. Connections for a Hoist Controller, with an Electric Limit Switch

SCHEME OF MAIN CONNECTIONS



SEQUENCE OF CONTACTORS

Con	Hoist						Off	Lower					
	6	5	4	3	2	1		1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3						○							○
4	○	○	○	○	○	○		○	○	○	○	○	○
5							○	○	○	○	○	○	○
6							○						
11	○	○	○	○				○	○	○	○		
12	○	○	○					○	○	○			
13	○	○						○	○				
14	○							○					

FIG. 346. Connections for a Hoist Controller

With a mechanical limit switch. Switches Nos. 7 and 8 are normally open and Nos. 9 and 10 are normally closed

as many features in common as practical. The various sizes of controllers may differ in the number of resistor notches, but the scheme of connections is the same and the same resistors may be used for a given horsepower with either magnetic or manual controllers. If the number

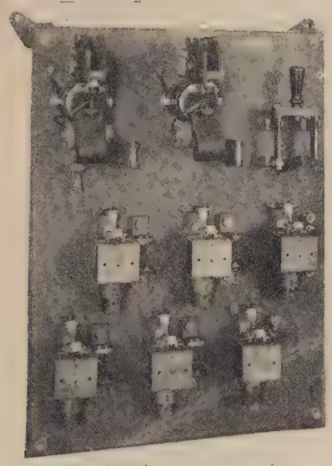


FIG. 347. Crane Protective Panel

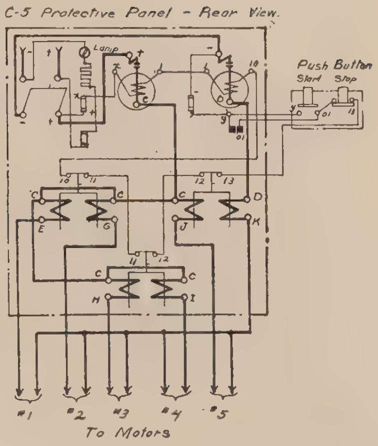


FIG. 348. Diagram for a Five-motor Protective Panel

of resistance connections is different, the terminals on the resistors may readily be shifted to take care of this condition. The speed torque curves of the motors are identical (Fig. 342), the highest and lowest speeds being the same for any controller and the intermediate speeds depending on the number of notches. Lever-type handles are desirable for both the manual controller and the master switch of the magnetic type; the forward movement lowers the load and the reverse movement connects the motor for hoisting.

In selecting controllers for a given installation, various sizes of motors should be tabulated and two or possibly three sizes of controllers selected from the entire range. This will reduce the spare parts required to a minimum. Ordinarily two sizes of contacts and arc boxes should give the proper range for an ordinary establishment. Manual controllers for this application are described in Chapter XII.

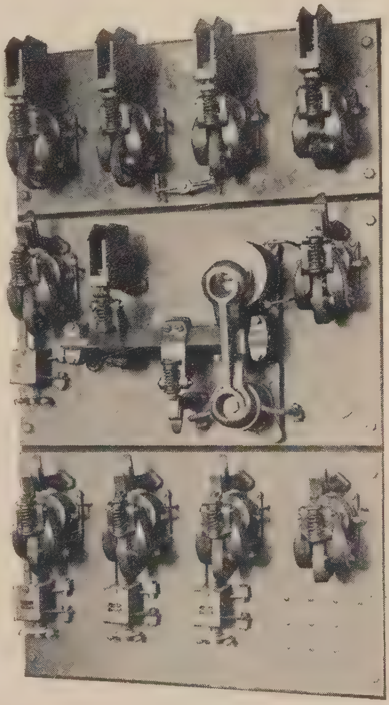


FIG. 349. Magnetic Contactor Control Panel Using Cast Iron Contactors

The magnetic contactor controllers are illustrated in Figs. 349 and 353. One of these has cast iron, the other pressed steel contactors.

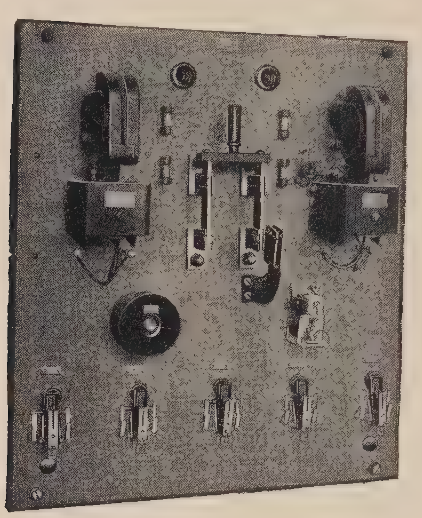


FIG. 350

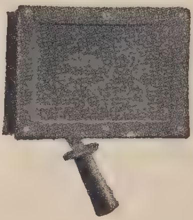


FIG. 351

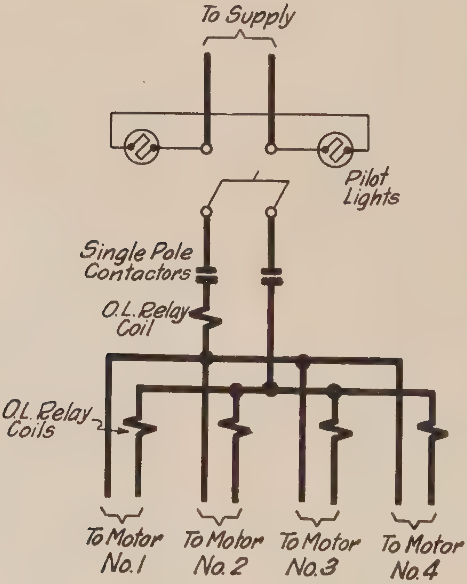


FIG. 352

FIGS. 350, 351 and 352. Crane Protective Panel Safety Switch and Diagram

When the controller is in the off position, contact *6* (Fig. 357) is closed, providing a dynamic brake path through the series field and a small section of resistance. This low resistance gives a suitable braking torque for stopping from slow speed. If the operator should be lowering a heavy load at full speed and move from full speed quickly to the off position, he would get an abnormally heavy dynamic braking current and torque which might seriously strain the mechanical structure and at the same time throw an abnormal load on the electrical equipment. When a magnetic contactor controller is used, automatic deceleration is obtained with the same relays that provide acceleration if the controller is on one of the running notches. Ordinarily this is sufficient, as the operation of the crane requires a considerable amount of skill in handling the load and a good operator would not attempt to stop his load from full speed without first slowing it down, but in some installations it has been thought advisable to provide automatic deceleration when the controller is thrown to the off position from full speed with a heavy load. Several methods

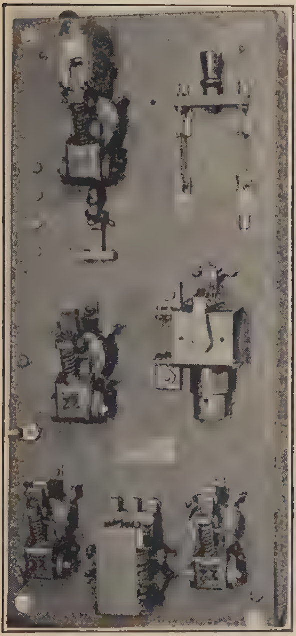


Fig. 353

Fig. 354

Fig. 353. Magnetic Contactor Control Panel

Using pressed steel contactors and multiple finger relays

Fig. 354. Hot Metal Ladle Crane Equipped with Magnetic Control

for accomplishing this have been proposed. One method is to provide relays connected across the motor armature which are held in by counter e.m.f. Relays of this kind are adjusted to drop out at the proper voltage but dirt and moisture may change the setting.

Another scheme provides a two-pole, protective relay which is closed when the motor is operating at one of the higher speeds. This relay maintains the magnet circuits to contactors *2*, *4* and *5* so that these contactors remain closed and contactor *6* is kept open until the last resistance switch has been closed. If the controller handle is thrown suddenly from full speed to the off position, the resistance contactors close automatically in the same way as for acceleration, the current limit relays maintaining the dynamic brake current at its proper value. When the last contactor closes, it opens an interlock which opens the protective relay and allows the motor to be disconnected from the line and closes switch *6*.

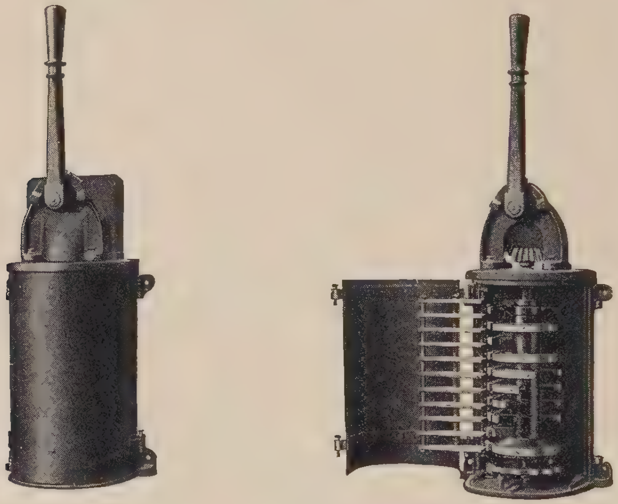


FIG. 355. Six-point Master Switch

This switch is of the drum type with a lever handle. It can be used with the controllers shown in Figs. 349 and 353.

Devices of this kind will guard against abuse to the controller but add some complication. They also prevent the operator obtaining the emergency stop in case of accident. It is, therefore, a question whether it is better to permit the operator to obtain emergency dynamic braking at will, relying on his judgment not to use it unnecessarily, or to add the complication of a protective relay.

Manual controllers require the use of a crane protective panel for automatically disconnecting the motors from the line in case of overload.

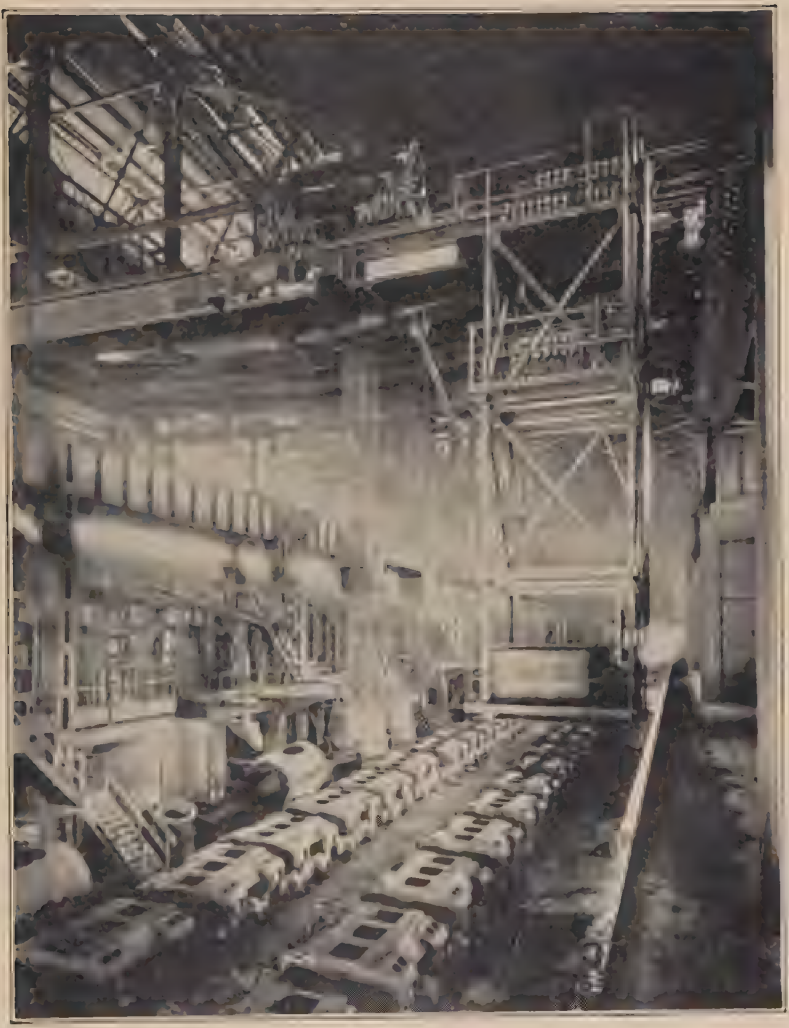
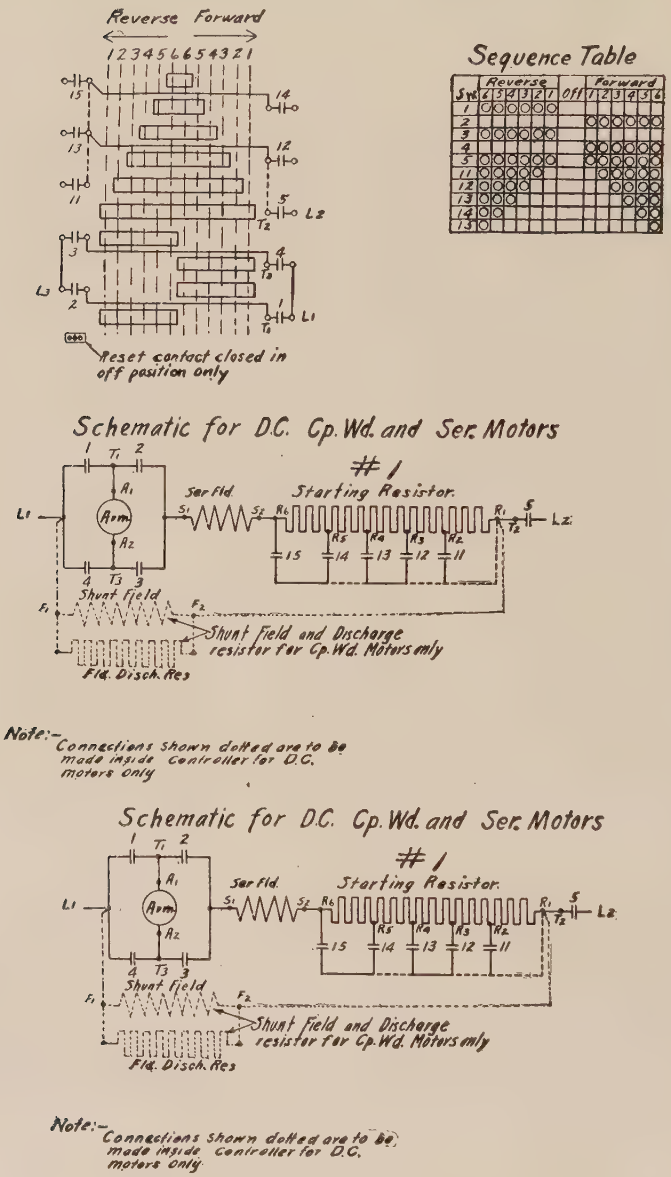


FIG. 356. Magnetic Switch Control on 150-Ton Crane

Magnetic Switch Control Panels shown in top decks (see arrows). Hoist is equipped with dynamic brake


Reverse
Forward
1 2 3 4 5 6 6 5 4 3 2 1
15
14
13
12
11
5
L2
T2
3
4
T3
L3
2
1
L1
T1
Reset contact closed in off position only
Sequence Table
Schematic for D.C. Cp.Wd. and Ser. Motors
1
T1
2
#1
A1
Ser Fld.
Starting Resistor.
L1
Arm
S1
S2
R6
R1
5
L2
T2
A2
R5
R4
R3
R2
15
14
13
12
11
4
T3
3
Shunt Field
F1
F2
Shunt Field and Discharge resistor for Cp.Wd. Motors only
Fld. Disch. Res
Note:— Connections shown dotted are to be made inside Controller for D.C. motors only
Schematic for D.C. Cp.Wd. and Ser. Motors
#1
Starting Resistor.
Note:— Connections shown dotted are to be made inside Controller for D.C. motors only

	Reverse							Forward					
Sw.	6	5	4	3	2	1	Off	1	2	3	4	5	6
1	○	○	○	○	○	○							
2								○	○	○	○	○	○
3	○	○	○	○	○	○							
4								○	○	○	○	○	○
5	○	○	○	○	○	○		○	○	○	○	○	○
11	○	○	○	○	○				○	○	○	○	○
12	○	○	○	○						○	○	○	○
13	○	○	○								○	○	○
14	○	○										○	○
13	○												○

FIG. 357. Diagram of Connections for Reversing Controller

This set of diagrams illustrate the different connections of the cam type of controller, Fig. 340. The top view shows a development of the cams. The second view is a scheme of connections for d-c. motors and below are the connections for a-c. motors. These connections are the same as for the magnetic controller. The dotted connections to shunt field windings of a d-c. motor are not used on ordinary cranes as the motors are usually series wound

Panels of this kind are illustrated in Figs. 347, 351 and 360. Two magnet contactors are provided which are actuated by a number of overload relays. There is one relay for each motor circuit and one relay in the common return circuit. If any one of the relays operates due to overload, it will open the magnetic contactors and cut the power off the crane. The magnetic contactors may be closed by pressing a reset button or the manual controller may be provided with means for resetting the contactors by moving it to the off position. Sometimes an energy switch or button is provided for opening these contactors in case of accident.

The protective panel is usually provided with a knife switch arranged for locking in the open position, also with a lamp receptacle connected to the line side of the knife switch, so that the repair man can attach a lamp cord to provide light when making repairs or inspecting the equipment. The overload and low voltage protective features provided by such a panel may be incorporated in the controller when it is of the magnetic type. Whether such a panel is used with magnetic contactor control depends upon local conditions and on personal preference. Such a panel, however, should always be used with manual controllers.

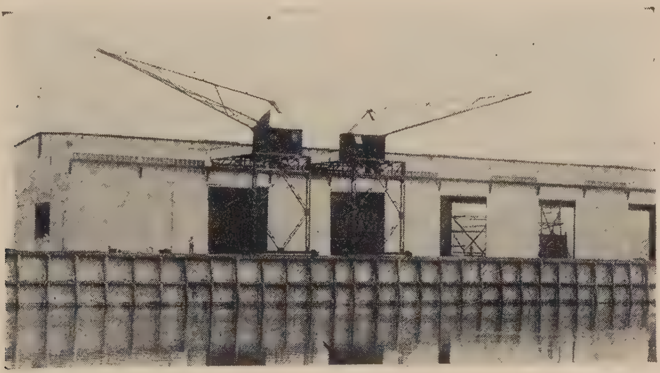


FIG. 358. 1.5-Ton Semi-portal Crane

This crane is equipped with a 35-hp. hoist motor; 15-hp. crane-travel motor and 7.5-hp. rotating motor

A limit switch should be included in every crane equipment, one switch for each hoist. These switches are so designed that the motor is stopped when the hook reaches a predetermined position in its upper travel. Limit switches are built in a number of different forms and types. They may either switch the motor direct or they may be in the form of a master switch which actuates contactors on a control panel or protective panel. The switch may be reset by reversing the controller, or it may require to be manually reset.

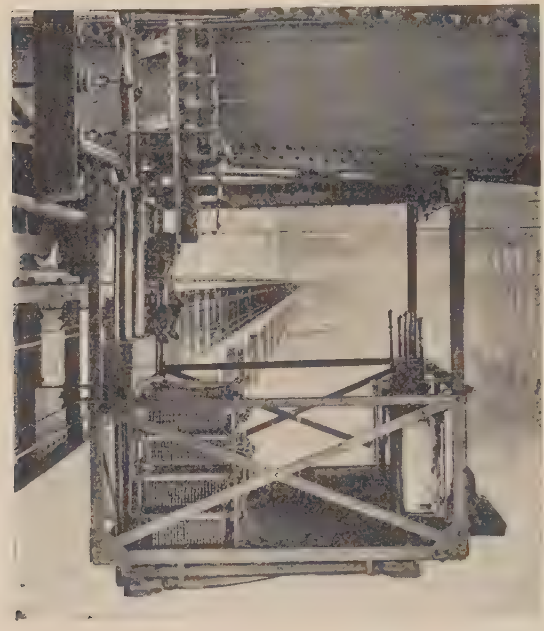


FIG. 359. Operator's Cab of a Traveling Crane
Showing cam controller and crane protective panel

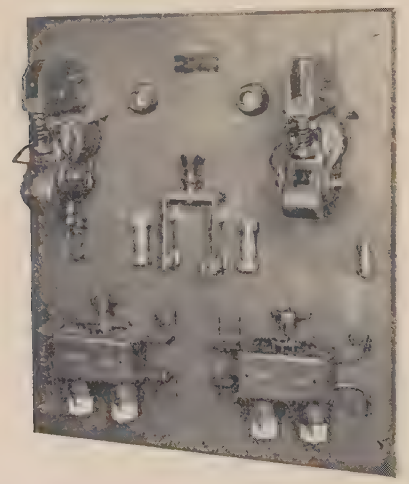


FIG. 360. Crane Protective Panel

Fig. 361 illustrates a form of switch used to switch the main circuit of the motor. This is a two-pole double-throw switch, the connections being illustrated in Fig. 362. The switch is located on the trolley, together with the dynamic brake resistance. When the hook reaches the upper limit of travel it lifts a weight which gradually moves the switch arm toward the safety position. After this arm has been moved far enough, it trips a catch inside of the switch, which causes one pair of contacts to open and the other to close. This disconnects the motor from the power supply and short-circuits the armature through a series field and an external resistance, which gives a quick stop by dynamic braking. By reversing the controller, the motor will operate the hook in the downward direction at a slow speed. This allows the weight to follow and restores the limit switch to its normal position by tripping a catch and moving the switch quickly to the normal position.

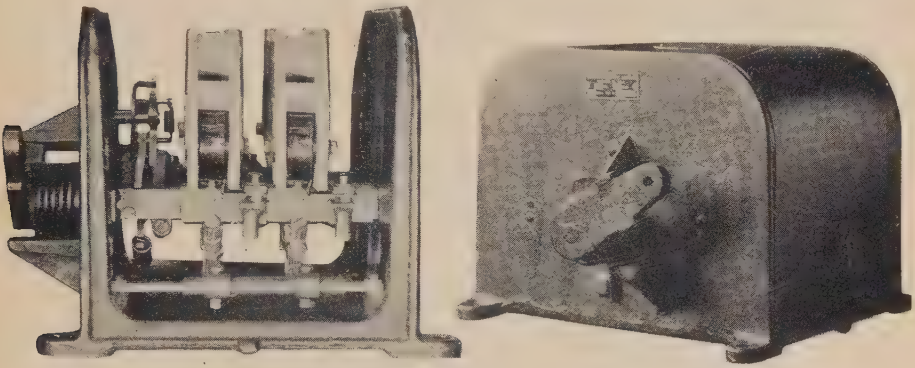


FIG. 361. Crane Limit Switch

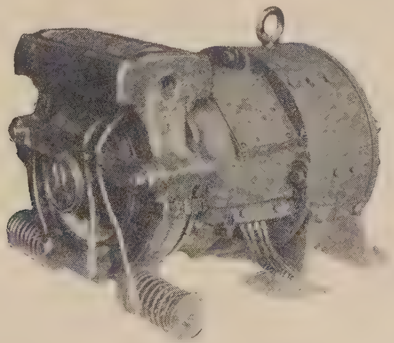


FIG. 362. Small Magnet Brake Mounted on the End Frame of a Crane Motor

When a switch of this type is used the circuit is opened at the motor and an emergency circuit established without the use of a pilot or auxiliary control circuit. If the limit switch is of the master switch type, at least one extra trolley will be required for a control wire and the emergency brake circuit would be fed through several trolleys, which introduces an additional hazard.

The switch described is automatically reset on reversing of the motor. Some designs of limit switch must be reset by hand. This means that the operator must leave the cab and climb up onto the bridge in order to reach the switch which is mounted on the trolley. It is pointed out that the inconvenience caused the operator is desirable, as it prevents him from running into the upper limits of travel and makes him more careful in manipulating his crane. On the other hand, the resetting of this switch causes the operator to expose himself to injury, and it is a question whether he should be subjected to this additional personal hazard. Devices can be used to indicate the number of times the limit switch has been operated and means taken to penalize the operator if it is thought necessary to do so.

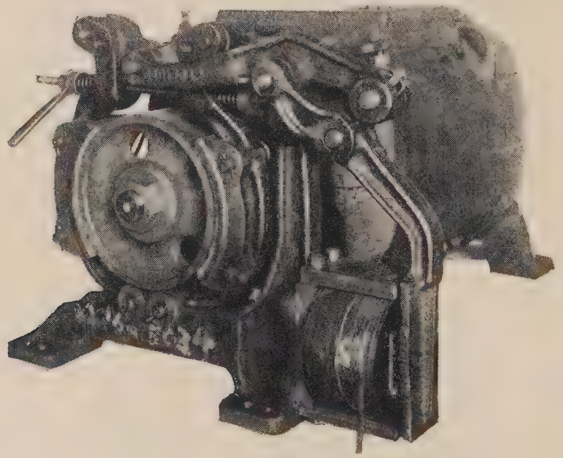


FIG. 363. Large Brake Mounted Separately from the Motor

All hoist motors on cranes are equipped with magnet brakes. These are usually shoe brakes released by a magnet and applied by a spring. The magnets are usually series wound and are designed to release the brake at not over 40 per cent of the rated current of the motor and to maintain the brake in the release position down to at least 10 per cent of the rated current of the motor. The coil should be connected in the circuit in such a way that no current will flow through it when the controller is in the off position. A few applications, such as ore bridges, have a wider range of current than is usual with ordinary cranes and it is, therefore, necessary to wind the brakes with a shunt coil. In order to make brakes quick acting, the shunt coil has relatively few turns and is connected in series with a resistance. Sometimes an additional resistance is shunted across the coil to take up the discharge. Large brakes actuated with coils arranged in this manner are quick in operation, and have proved very satisfactory.

Smaller motors may be provided with brakes mounted on the motor frame, as shown in Fig. 362. Larger motors have the brakes separately mounted, Fig. 363. Both arrangements have their advantages and disadvantages. Ordinarily the small motor is easy to handle, as the entire motor, including the brake, can be taken off the crane and another one substituted when repairs are required. Larger motors are more difficult to handle and there is an advantage in having the brake mounted separately.

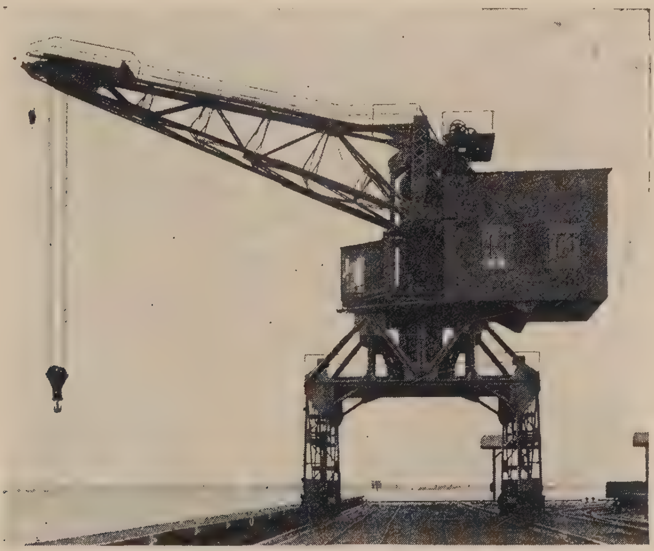


FIG. 364. 75-Ton Full-portal Crane

This crane has a 54-ft. radius and is 54 ft. from track to pivot pin. Hoist motor, 80-hp.; crane travel motor, 25-hp.; rotating motor, 33-hp.

A good example of a special design of heavy cranes is illustrated in Fig. 365. This shows a 150-ton electrically-operated revolving pontoon crane, which is, perhaps the largest ever constructed in the United States. The pontoon contains a complete boiler plant and an engine-driven generator, which supplies the electric current for operating the various mo-

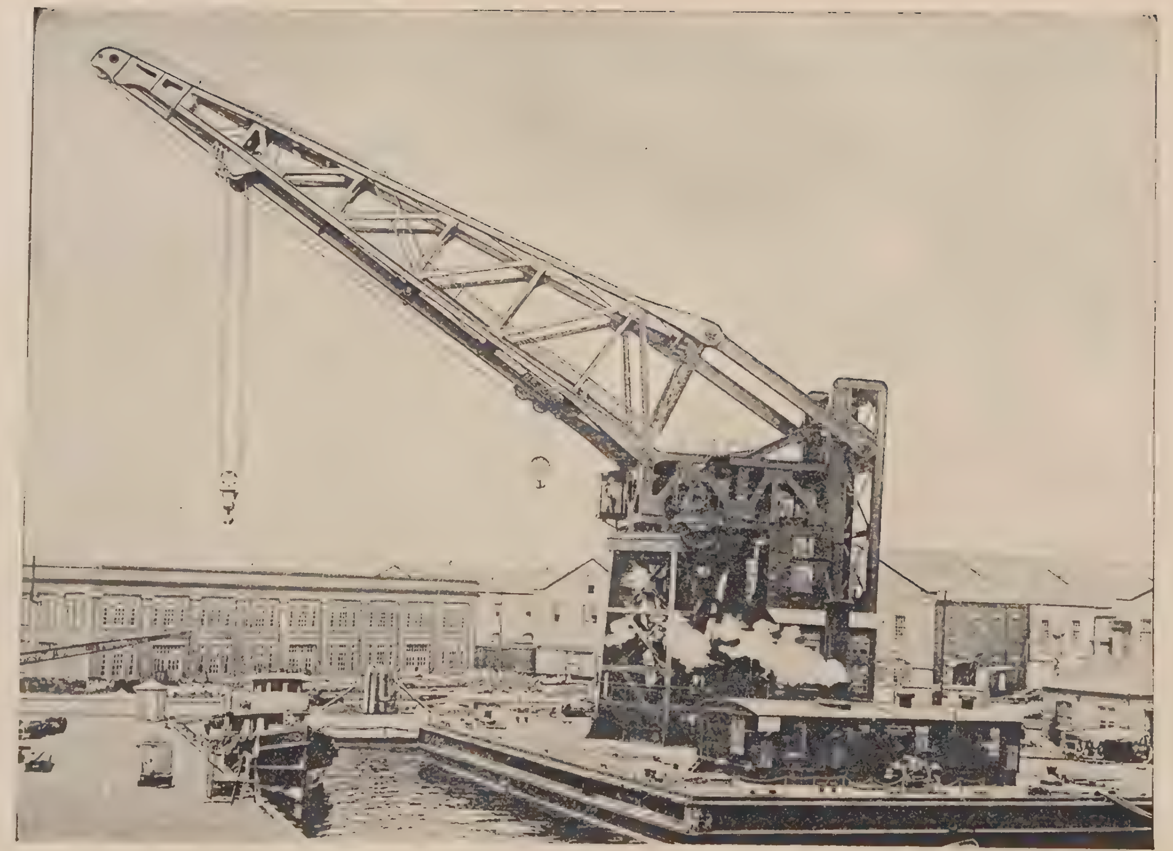


FIG. 365. 150-Ton Electrically-operated Revolving Pontoon Crane

Pontoon 150 feet by 85 feet and 15 feet deep. Two 60-hp. main hoisting motors and one 60-hp. auxiliary hoist motor. Two 60-hp. rotating motors. Two 60-hp. boom hoist motors.

tions of the crane. The crane is controlled from a small house mounted above the pontoon deck by means of master controllers; one operator is able to control all of the motions of the crane. When the load is lowered, the motors operate as generators and, in case of accidental interruption of electric current, the crane motions are automatically locked by means of friction brakes to prevent the possibility of dropping the load. The crane motions consist of a main hoist of 150 tons divided into two parts of 75 tons each. These hoists are fixed on the boom. In addition, there is an auxiliary hoist of 25 tons capacity, which is movable up and down the boom. A rotating motion is obtained by two 60-hp. motors and the boom hoist is operated from the vertical to an angle of 30 degrees by two screws operated from 60-hp. motors. In addition to the crane proper, the pontoon is equipped with four electrically-operated capstans, one in each corner.

SUMMARY OF CHAPTER XXX

Cranes may be classified as jib, gantry, traveling, tram, or locomotive cranes. The function of a crane is to hoist and transport loads short distances. The traveling crane consists of a bridge-like structure which moves sidewise. In addition to the bridge travel, the load is moved crosswise by means of the trolley travel. The load is lifted in the hoisting movement. Besides the main hoist an auxiliary hoist may be employed, also an additional trolley, so that a total of seven motors may be required (two trolley motors, one main and one auxiliary hoist motor for each trolley, and the bridge motor). When the load is being lowered the motor is connected as a generator, affording dynamic braking.

The manual controller is lighter and cheaper, the wiring connections are simpler, but more power is required to operate it, the contacts are less durable, and automatic acceleration and retardation are not provided. The magnetic controller is more durable, easier to operate, the arcing takes place at a distance from the operator, and small space is required for the master switch. Which is preferable depends upon the size and frequency of service of the crane.

Overload and other protective features are provided in a protective panel. Overtravel of the hoist or other motion is prevented by limit switches. In addition to the dynamic braking feature, hoist motors are provided with a magnetic brake.

CHAPTER XXXI

CAR DUMPERS

Action of car dumper described—barney haul—cradle hoist—pan or apron.

The car dumper is a special machine designed for unloading ore or coal from open type railway cars. The apparatus consists of two essential parts—the barney haul and the cradle hoist.

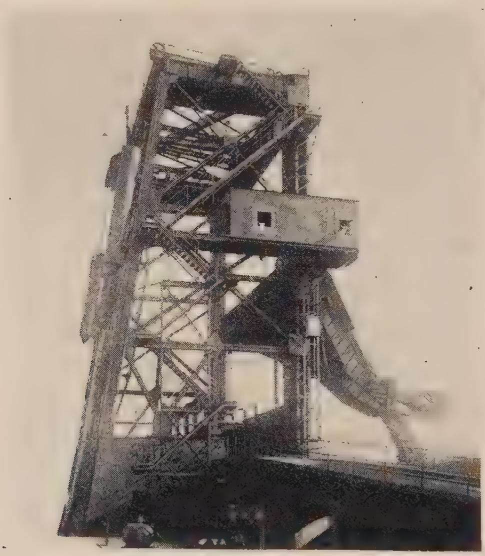


Fig. 366. Car Dumper

Showing the incline on the approach side. This dumper is used for loading coal into boats and is provided with a special form of pan and chute for this purpose

A train of loaded cars is placed on a slight incline approaching the car dumper. An individual car is detached and passes down the incline to the barney haul, which consists of a small car with a pusher arm projecting above the track between the rails, attached to a cable driven by an electric motor. The arm engages the rear of the car and pushes it up an incline to the cradle hoist. The car is fastened securely in the cradle by clamps, shown in Figs. 367 and 369, which engage the top of the car and hold it firmly against the rails. These clamps consist of vertical members which are curved into hooks at the top. There are several of them on each side of the car, set high enough to clear the largest car and held down by counterweights, such as the small rectangular counterweights shown in Fig. 367. When the cradle is hoisted they engage the top of the car, exerting sufficient force to retain the car in place when the cradle turns it over. By the use of counterweights a very flexible form of clamping is obtained, which is entirely automatic in its operation.

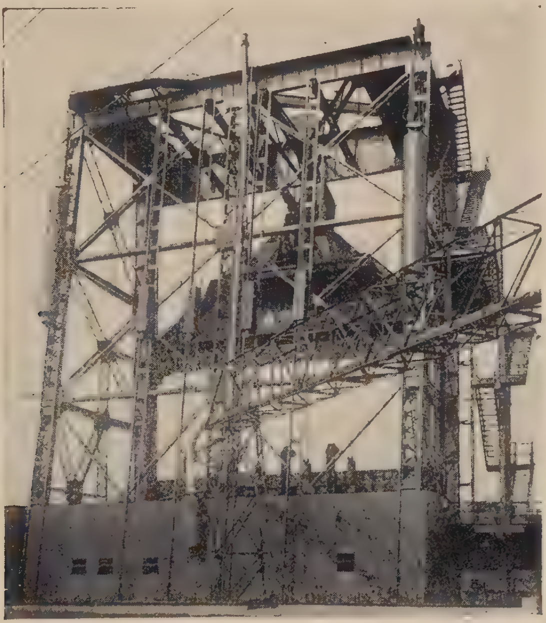
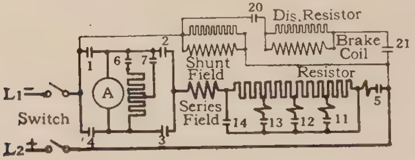


FIG. 367. Back View of Car Dumper of Fig. 366.

Clamping bars may be used instead of hooks as shown in Fig. 369. The cradle hoist lifts the car to a fixed elevation and turns it over, emptying the contents of the car onto an apron provided with a chute for directing the contents into the proper place. This method of unloading is used extensively in connection with coal and ore. The material may be loaded onto a conveyor, into a boat or a hopper car. The empty car is returned to the track level and the clamps removed. The next loaded car pushes the empty car onto an incline located on the other side of the cradle hoist. The empty car descends by gravity to an assembling track or switch, where it is taken care of in the usual way.

BARNEY HAUL

The barney haul is usually operated by a direct-current compound-wound motor, although a series motor may be used where there is sufficient friction to eliminate any danger of over-speeding. The controller is usually of the rheostatic reversing type, provided with one armature shunt point to give a slow speed when the barney engages the car. A series or compound motor is able to exert the heavy torque required during the period of moving the car up the incline. On the reverse motion the weight of the barney is insufficient to overhaul the cable; it is therefore necessary to operate the motor drive in the reverse direction. A series or a compound motor gives a high speed return under this light load. In calculating the size of motor and control the heating effect is based upon the period of heavy load during hoisting and the light load on the return stroke. The motors run from 150 to 300 hp., at either 230 or 500 volts. The controller is of the magnetic contactor type Fig. 368. Limit switches are provided to stop the motor automatically at each limit of travel. Both the gear type and the track type limit switches have been used.



SCHEME OF MAIN CONNECTIONS

SEQUENCE OF CONTACTORS

Con	Dwn	Off	Up					
			1	2	3			
1			○	○	○	○	○	○
2	○							
3			○	○	○	○	○	○
4	○							
5	○		○	○	○	○	○	○
6			○	○				
7			○					
11					○	○	○	○
12						○	○	○
13							○	○
14								○
20	○		○	○	○	○	○	○
21	○		○	○	○	○	○	○

FIG. 368. Diagram of Connections for Barney Haul

CRADLE HOIST

The motors for the cradle hoist are of the direct-current series type. Sometimes a single motor is used, for other applications—two motors. Where the barney haul requires only half the horsepower of the cradle hoist, the use of three motors of the same rating makes a good arrangement. The armatures and other spare parts of the motors remain the same, the only difference being the field windings.

While the loaded car is being hoisted, the maximum amount of torque is required. After the proper height has been reached and the car begins to turn over, the load decreases but still remains positive due to the arrangement of counterweights. In returning the empty car the motor first operates under a friction load while swinging the cradle over to the upright position of the car. The cradle and car are then lowered under dynamic braking to the track level. The cradle is counter-balanced to make the work done during the total cycle as small as possible.

The controller connections, Fig. 370, provide for full reverse with dynamic braking in the lowering. The controller consists of magnetic contactors operated from a master switch. The limit of travel in both directions is controlled by limit switches, either of the gear or track type. The motors range in size from a total of 250 to 400 hp., sometimes divided between two motors. Usually the single motors do not exceed 350 hp.

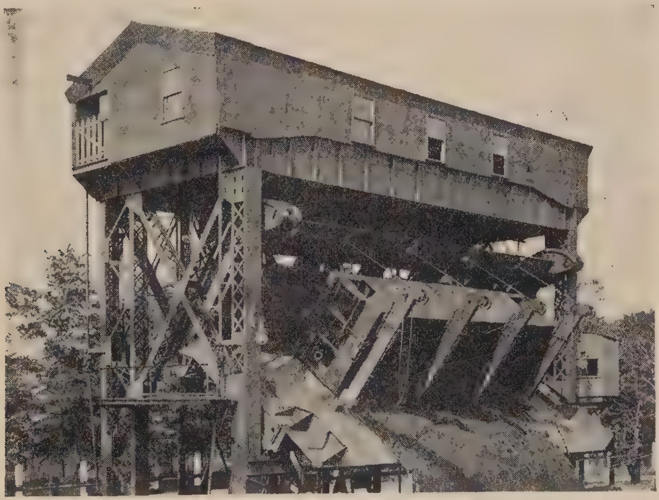
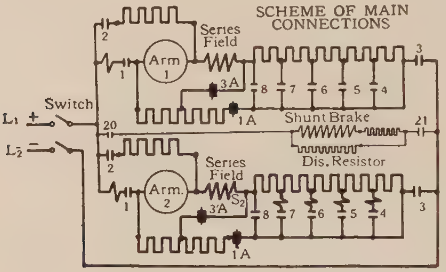


FIG. 369. Car Dumper Discharging the Coal from a Car
The car is held against the track by means of bars instead of hooks

The distance of the vertical hoist before the car is turned over depends upon the applications. In some cases this hoist may be 40 to 50 ft., in other cases only a short distance. Where the vertical travel is considerable, it is usually necessary to slow down the cradle where the motion changes from vertical to rotating. In coming back, the rotating motion is slowed down where it changes to vertical. This slowing down is to avoid shocks when the cradle enters and leaves the hooks or trunnions.

The above description is general. It applies in the main to various commercial types of car dumpers, each particular design embodying ingenious features for taking care of the details. The arrangement of the barney differs with various companies. It is necessary to return the barney, so that it will pass underneath the next car. This may be done by a system of two track levels or by an arrangement for rotating the arm into a horizontal position during the return part of the travel. The details of changing the motion of the cradle from the vertical hoist to the rotating motion differ in various designs. The car dumpers illustrated in Figs. 366 and 371 employ an ingenious arrangement to permit the operator on the outer end of the pan to get back and forth to the main cab. It consists in a duplicate set of controllers for hoisting the pan so that the operator may bring the hinged end of the pan back on a level with the stationary cab and then raise the pan to a horizontal position to permit him to walk from his cab to the main cab. Various designs of pans or chutes are employed for directing the contents of the car in the desired manner.



SEQUENCE OF CONTACTORS

Con	Hoist					Off	Lower					
1	○	○	○	○	○							
2							○	○	○	○	○	○
3	○	○	○	○	○		○	○	○	○	○	○
4	○	○	○	○	○		○	○	○	○	○	
5	○	○	○	○			○	○	○	○		
6	○	○	○				○	○	○			
7	○	○					○	○				
8	○						○					
1A						○	○	○	○	○	○	○
3A						○						
20	○	○	○	○	○		○	○	○	○	○	○
21	○	○	○	○	○		○	○	○	○	○	○

FIG. 370. Scheme of Connections for Cradle Hoist

Using two motors in parallel. Each motor has a separate set of resistors short-circuited simultaneously by double pole contactors. The acceleration is by current limit relays and the relay coils are shown in the circuit of No. 2 motor. The motors are geared together rigidly and must be accelerated as a single unit

PAN OR APRON

Where the coal or ore is loaded into the vessel, an adjustable pan or apron provided with a chute is furnished, the nozzle of which can be turned in different directions. This arrangement is illustrated in Fig. 366. The pan is raised or lowered by a pair of screws, one of which is attached to each upright. These screws are driven by reversible motors with the ordinary rheostatic control. The pan is hinged to the two uprights of the car dumper and the outer end is raised or lowered by means of an electric motor. The control for this motor is similar to the control for the cradle hoist, only much smaller. It provides for rheostatic control in the hoisting direction and dynamic braking in lowering.

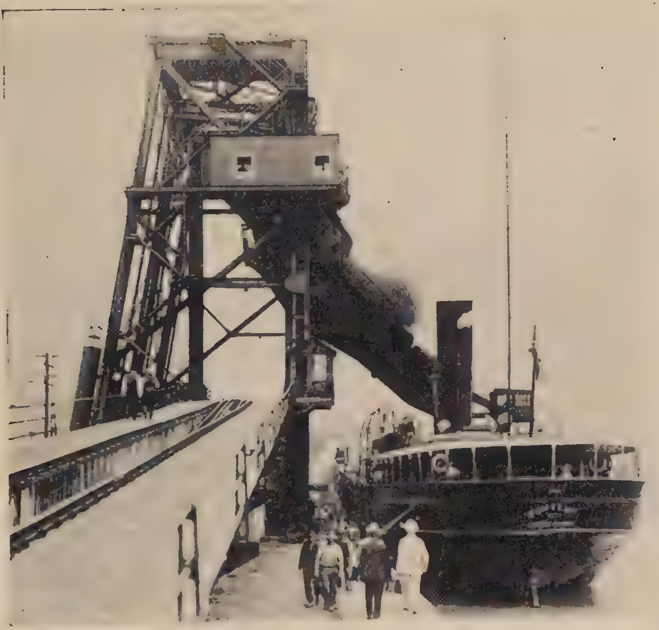


Fig. 371. Car Dumper Loading Coal into a Boat

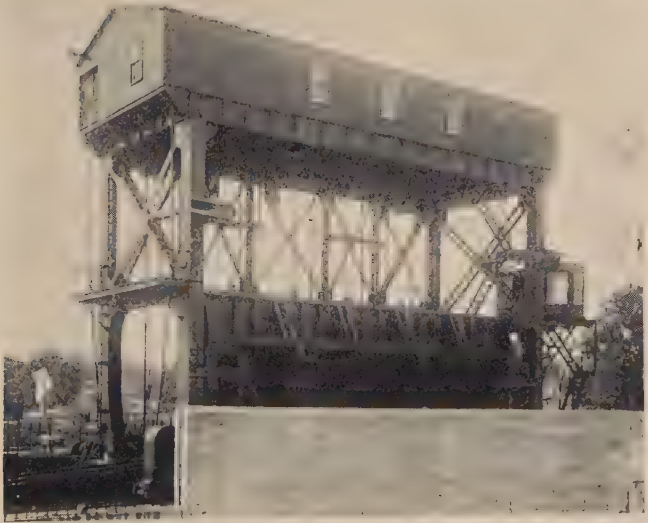


Fig. 372. Car Dumper Arranged for Dumping Coal or Ore into a Yard Separated from the track by a wall. The coal or ore is taken from this point by a bridge with a grab bucket. This form of car dumper is arranged for moving along the wall and is carried on a special track

The chute is provided with a small motor for rotating it. The operator is located in the cab immediately above the chute and controls the height and location for the opening in the chute by means of the controllers just described.

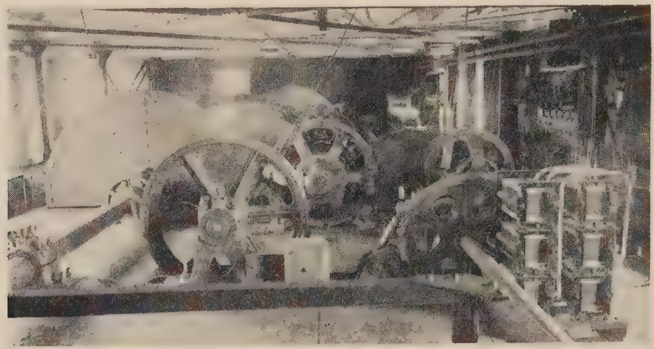


FIG. 373. Motors and Controllers for Operating Car Dumper

SUMMARY OF CHAPTER XXXI

A car dumper unloads ore or coal from open railway carts. It consists essentially of a barney haul and a cradle hoist. A car having been disengaged from the train, the barney haul, a small car with a pusher arm, delivers it to the platform of the cradle hoist. Here the car is clamped to the rails of the platform and lifted and turned over and dumped on the apron or pan, from which the material is chuted to a conveyor, boat, or hopper car

CHAPTER XXXII

ORE AND COAL BRIDGES

Action of ore bridge described—hoist—trolley—bridge.

Ore bridges are used for the handling of ore and coal, principally on the Great Lakes. During the navigation period, ore is shipped from the Lake Superior region to the lake ports in the East, and coal is shipped back. The ore boat is a long vessel made up almost entirely of cargo space. The propelling machinery is usually at the rear, which leaves the body of the boat free for cargo. The ore is loaded into the boats at the Lake Superior ports from bins by means of chutes. When the boat reaches its eastern destination in the neighborhood of Cleveland or Buffalo, the ore is taken out of the boat and either loaded in cars for transportation to the blast furnaces or placed in stock piles. The coal is then loaded into the boat from cars by means of a car dumper and is taken out of the boat at the Lake Superior ports by means of an unloading bridge.

An ore or coal bridge, Fig. 374, consists of a structural steel span supported on two piers. These supports are mounted on tracks and moved by electric motors. On the bridge is a run-way supporting a trolley, which is moved forward and back on the bridge by electric motors and carries the hoisting mechanism for raising or lowering the clam-shell bucket. Usually the operator rides in this trolley, familiarly known as a "man trolley." The bridge is moved along the tracks until the clam-shell bucket is in position above the hatchway. The bucket is lowered into the boat and lifts the ore or coal up through the hatchway, carrying it back to bins or a stock pile. The bins are used for loading cars in the usual manner. During the summer, a surplus of ore is accumulated at the Great Lake stations in large piles known as "stock piles." At the time of unloading, the ore is graded, so that the burden in the clam-shell bucket may be dropped close to the dock or a considerable distance back, depending upon the location of that particular grade of ore.

Special machines are frequently used for the purpose of unloading the ore from the boat. Where such machines are employed, the ore bridge is used for transferring the ore from the unloader proper to the stock

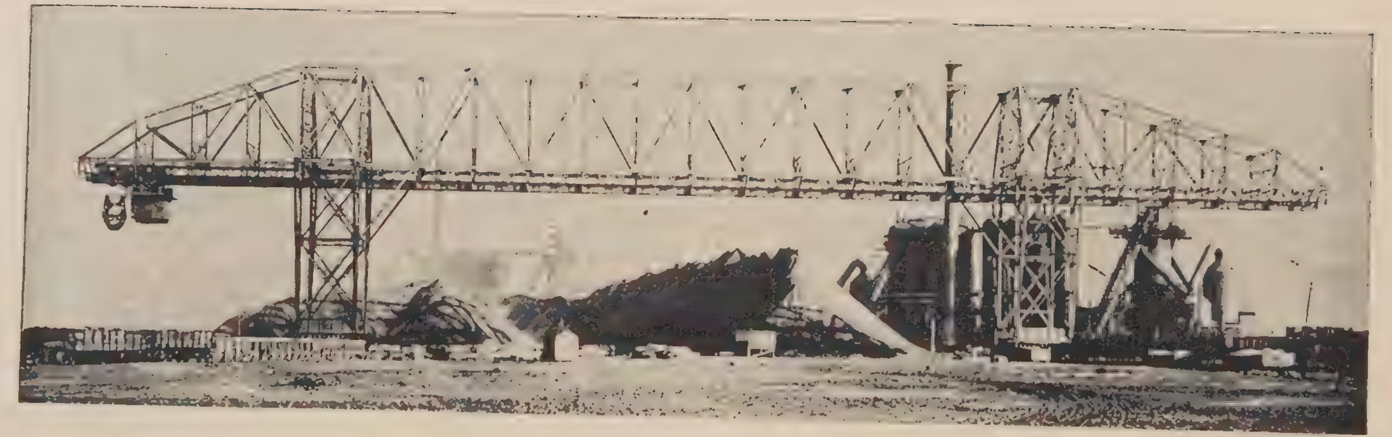


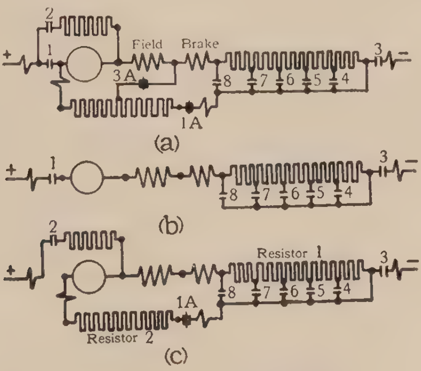
FIG. 374. Ore Bridge

Operated by direct-current motors and controllers. A pile of iron ore is shown under the bridge and blast furnaces at the right and in the background pile or bins. Where the ore bridge is used for unloading the boat, provision is sometimes made for twisting the bucket through 90 degrees to facilitate picking up the ore in the hold of the boat.

The application of motors and control to an ore or coal bridge divides itself into three distinct classes; *viz.*, hoist, trolley and bridge.

HOIST

The hoist is equipped with two drums, one drum handling the shell line and the other the closing line. The shell line is attached directly to the stirrup of the bucket, while the closing line is attached by levers in such a manner that pulling on the closing line causes the jaws of the clam-shell to come together and retain the load. In picking up a load, the bucket spades are in a vertical position, with the closing line slack. The bucket is then lowered into the ore or coal and the closing line pulled up. The tension on the closing line moves the two shells together, after which the hoisting may be done on both the closing and the shell lines. To discharge the burden, the load is held by the shell line and the closing line is slackened.

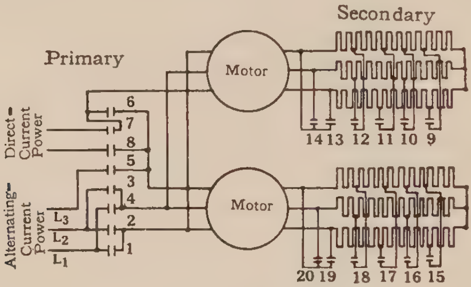


Notches	1	2	3	4	5	6	
Hoist – Close Switches	1-3	4	5	6	7	8	
Lower Kick Off Close Switches	1A-2-3						Method 1
Lower Brake – Close Switches	1A-3	4	5	6	7	8	
Lower – Close Switches	1A-2-3	4	5	6	7	8	Method 2
Off Position – Close Switches	3A						

FIG. 375. Connections of Direct-current Motors and Controllers for Hoist Installations

When only one hoisting motor is used, the two drums are controlled by clutches. Where two motors are used, one is connected to each drum, each motor having a separate controller and usually a separate master switch. By using two motors and adjusting the resistance, the proper tension can be kept on the closing and shell lines so that the bucket will not open until the operator changes the adjustment.

Direct-current Motors are series wound and operated as standard series motors in the hoisting direction. In lowering, a kick-off notch is provided which connects the armature and field in parallel across the line. This causes the motor to operate as a shunt motor. After the bucket has started down, there is always sufficient weight to overhaul the hoisting mechanism so that the armature generates through the series field and provides dynamic braking. After this braking circuit has been once established, the speed of lowering can be controlled by changing the resistance in the dynamic brake circuit. The motor may or may not be disconnected from the line, depending upon which condition gives the most economical operation.



Notches	1	2	3	4	5	6
Hoist- Close Switches	1-3-5-6	9-15	10-16	11-17	12-18	13-14-19-20
Lower-Close Switches	2-4-5-6	9-15	10-16	11-17	12-18	13-14-19-20
Brake- Close Switches	7-8	9-15	10-16	11-17	12-18	13-14-19-20

FIG. 376. Connections for Alternating-current Hoisting

Used in installation shown in Fig. 380

The schematic arrangement of such a control for a single motor is shown in Fig. 375. If two motors are used, two controllers are supplied, one for each motor. The switch marked *3A* in Fig. 375 (*a*) is closed only in the central or off position. This dynamic brake circuit does not include the magnet brake[1] coil; therefore, the friction shoes set and the motor is brought to rest.

The connections for hoisting are given in Fig. 375. (*b*) This is a straight rheostatic controller, the speed of hoisting being controlled by a cutting out of resistance in series with the armature and field.

The connections for lowering are given in Fig. 375. (*c*) On the first notch, the current comes in through switch *2* to a point between the armature and field. It passes through the field and brake magnet to the starting resistance and thence through switch *3* to the line. Another branch of current passes through the armature in the reverse direction and through a resistance to contact *1A* and thence to contact *3* and the line. This keeps the current flowing through the field in the same direction while it reverses the current through the armature, causing the motor to rotate in the opposite direction. After the motor starts, the load drives the motor as a generator, the circuit being through the field and resistance *1* to resistance *2* and thence through the armature, completing the circuit. When this condition is established, switch *2* may be opened. The motor then runs as a generator at its maximum speed. By successively

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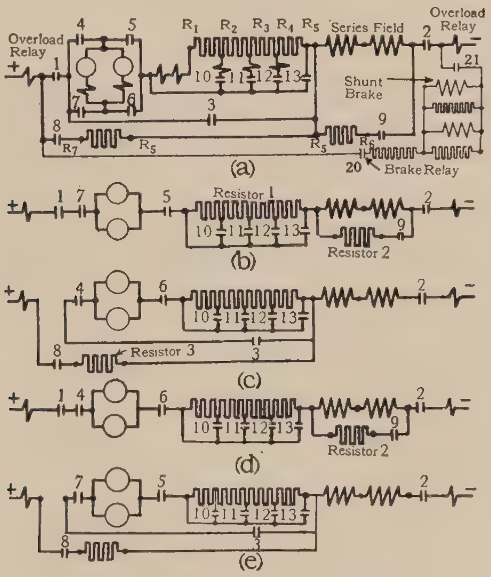
[1] By "magnet brake" is meant a friction brake which is set by a heavy spring and released by a magnet.



SEQUENCE OF CONTACTORS

Con.	Forward ←					Brake →					Off	← Brake					Reverse →				
1	○	○	○	○	○												○	○	○	○	○
2	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○	○	○
3						○	○	○	○	○		○	○	○	○	○					
4						○	○	○	○	○							○	○	○	○	○
5	○	○	○	○	○							○	○	○	○	○					
6						○	○	○	○	○							○	○	○	○	○
7	○	○	○	○	○							○	○	○	○	○					
8						○	○	○	○	○		○	○	○	○	○					
9	○	○	○	○	○												○	○	○	○	○
10	○	○	○	○			○	○	○	○		○	○	○	○			○	○	○	○
11	○	○	○					○	○	○		○	○	○					○	○	○
12	○	○							○	○		○	○							○	○
13	○									○		○									○
20	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○	○	○
21	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○	○	○

FIG. 377. Connections of Motors and Controllers for Trolley Applications

closing switches *4* to *8* inclusive, the resistance of this circuit is decreased and the speed of lowering decreased. In order to stop, the controller is moved to the central position, closing switch *3A*, in Fig. 375 (*a*), which sets the magnet brake and brings the hoist to rest.

Other methods of connecting the motor armature and field for lowering have been proposed, but they all follow the same essential arrangement, as shown in Fig. 375; namely, the motor is operated as a shunt generator for the kick-off or starting point and as a series generator for lowering. Sometimes a reverse current relay is placed in the armature circuit to disconnect the motor from the line automatically as soon as regeneration begins. If a heavy load is lowered frequently, it may be more economical to keep the motor connected to the line, so that power will be returned to the system. Usually, however, the bucket is lowered empty and hoisted with a load. It is trolleyed over to the proper point and the load dropped without lowering the bucket, as this saves time.

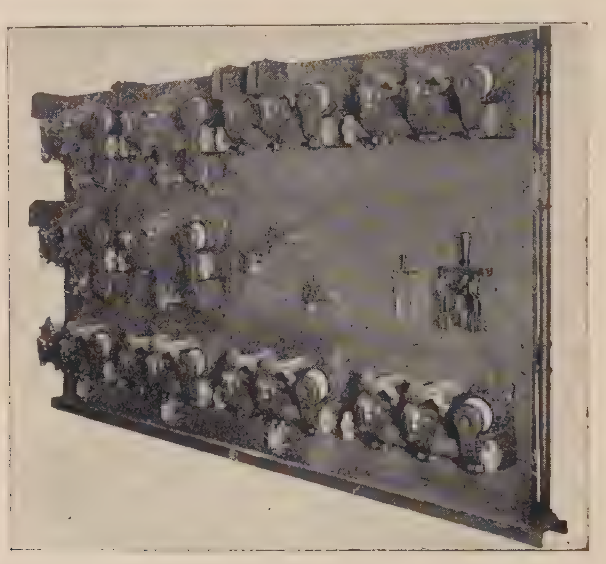


FIG. 378. Direct-current Control Panel

Designed for two motors and used in trolley applications. Double-pole switches are used throughout to insure that the direction and acceleration of the motors is maintained uniform

Alternating-current Motors.—Wound-secondary induction motors with external resistance have been in successful use for about ten years on bridges of this type. The control is shown diagrammatically in Fig. 376. For operation under power, the control does not differ in any way

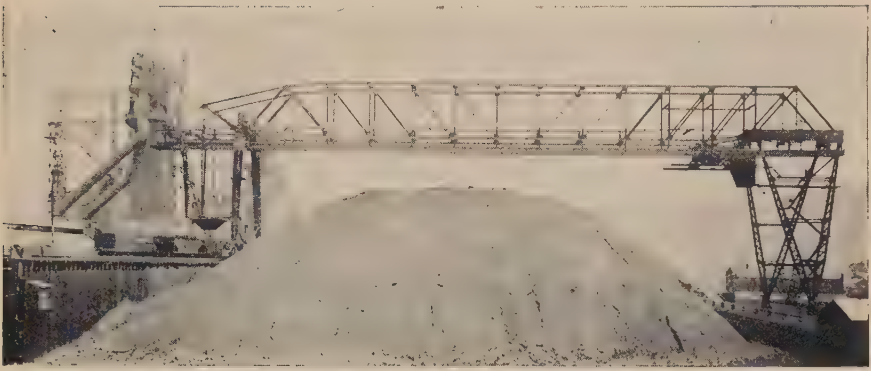


FIG. 379. Ore Bridge

Equipped with direct-current motors and controllers, and having a 10-ton bucket. Two motors are used on the hoist and one on the trolley. A large pile of iron ore is shown in the foreground and the blast furnaces in the background

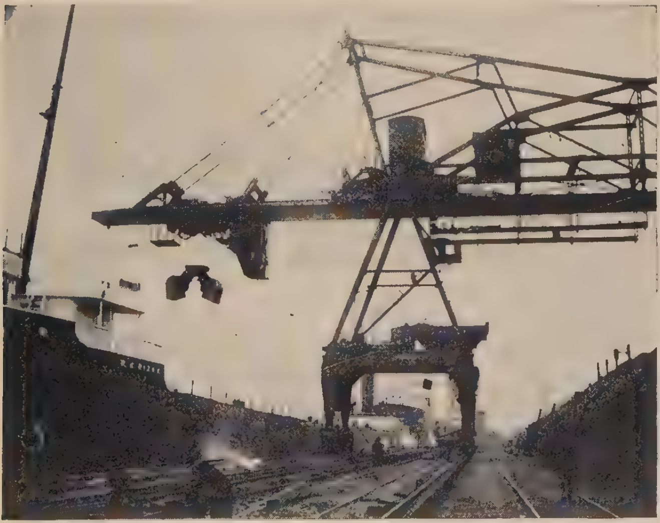


FIG. 380. Ore Bridge Unloading Coal from Boats

Showing pier leg of bridge, bucket and man trolley. This bridge was the first one which used alternating-current motors for coal handling and is equipped for dynamic braking. The bucket has a five ton capacity and this installation has been in successful operation many years from the standard reversing controller. The motor is connected to the line with all of the resistance in the secondary and this resistance is gradually short-circuited to bring the motor up to full speed. Dynamic braking is obtained by connecting the primaries of the motors in series to direct-current power, which is usually furnished by a motor-generator set. The resistance is inserted in the secondary. With the motor at full speed, the direct-current power provides a stationary field which produces the same effect as when the motor is at rest and the alternating-current rotating field is provided. As the resistance is reduced in the secondary of the motor, it is gradually slowed down until it operates at a very slow speed with the secondary short-circuited. The controller illustrated in Fig. 376 can be arranged for the same number of power and brake notches on either side of the off position when used for trolley applications. It is simplif or hoisting by omitting the brake connections for the upward tr f the bucket and reducing the number of power notches for the dow ward travel. These are details of the master

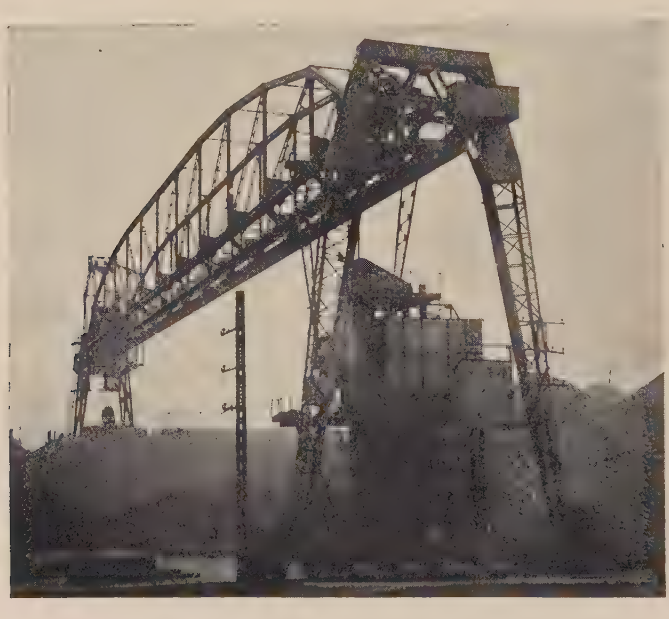


Fig. 381. Bridge Operated by Alternating-current Motors

Showing the 13,000-volt, high-tension transmission lines which are connected through sliding contacts directly to transformers mounted on the bridge, thus effecting a material saving in copper and insuring good voltage regulation at the motor. This is very important with alternating current, as the torque of induction motors varies as the square of the voltage switch connections. Sometimes a magneto, or small direct-current generator, is driven by the motor shaft to operate a relay for disconnecting direct-current power from the motor fields and applying the brake when the speed has been reduced to a predetermined value. This magneto may also be used for setting the brake in case of overspeed.

TROLLEY

The trolley runs on a horizontal track lengthwise with the bridge and carries the hoisting mechanism, and usually the operator. Two motors are generally used for operating the trolley, although a single motor may work out best with some mechanical arrangements. The usual method of control for a trolley provides for dynamic braking, as well as power connections. The central position of the handle represents the *off* or stationary position of the trolley. The movement on either side of the *off* position provides the dynamic brake connections. After the master switch handle has passed through these brake notches, it comes to the power notches for either forward or reverse connections. To start, the handle is moved through the brake notches and the power notches; in stipping, a gradual movement of the handle towards the central position applies the dynamic brake with increasing strength until the central position is reached, where the mechanical brakes are applied and the trolley is stopped.

The complete schematic diagram is shown in Fig. 377 (*a*) using two motors, the armatures of which are connected permanently in parallel and the fields in series. In the power position, shown in the second diagram, the motor is connected directly across the line and a shunt is provided around the series fields through switch *9* and resistance *2*. This shunt is necessary, as the field coils are designed to carry the full-load current of one motor only and the current of both armatures passes through the fields in series. Half of this current must be shunted in order to give normal field strength and to prevent overheating. The speed of the motor is controlled by closing switches *10* to *13* inclusive, which short-circuit the resistance in series with the armature. Fig. 377 (*d*) shows the same connection with the current passing through the armatures in the reverse direction.

The brake connections are shown in Fig. 377 (*c*) and (*e*), the only difference being the direction of current through the armatures. The shunt around the field coils is disconnected and current is applied through switch *8*, resistance *3*, the field coils and switch *2* to the line. The armatures are connected in the closed loop through the starting resistance and switches *3*, *4*, and *6*. This causes the motor to operate as a shunt generator, the amount of dynamic braking being controlled by closing switches *10* to *13* inclusive, which decreases the resistance in the armature circuit. When the mechanical brakes are released by an electromagnet, the magnet is provided with a shunt winding, which is disconnected in the *off* position. Where a single motor is used, no shunt con-

FIG. 382. Coal Handling Bridges at the Panama Canal

Equipped with direct-current motors and control, and having a capacity of 2.5 cubic yards. These bridges were originally used for handling concrete nection is required around the series field, as provided for in switch *9* and resistance *2*; otherwise, the connections are the same. Sometimes two motors are provided, each with a separate controller. When this is done, it is desirable to use double pole switches and common accelerating relays, Fig. 378, so that the rate of acceleration of both motors is

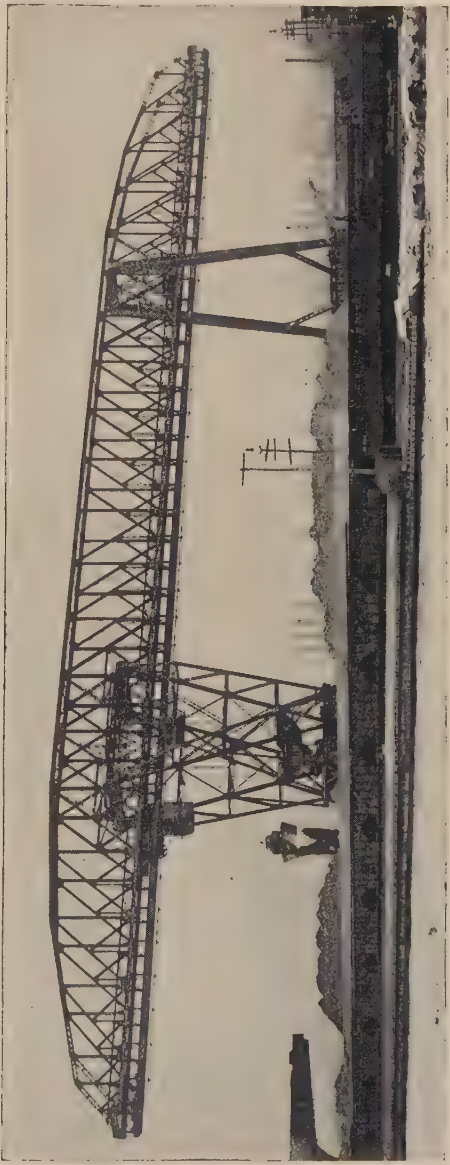


Fig. 383. 15-Ton Ore Rehandling Bridge

Equipped with direct-current motors and control maintained constant and there is no danger of connecting the motors to the line in reverse directions.

BRIDGE

One or two motors are provided on each pier of the bridge for moving it along the track. These motors are provided with an ordinary reversing controller having a slow-down point by using a resistance in shunt with the armature. The friction brake is released by a shunt magnet, which is disconnected, thereby setting the brake, only in the *off* or central position of the master switch. Usually, two separate master switches are used, as the two piers of the bridge may not always move at a uniform rate, due to slippage and other causes. If one pier moves faster than the other, the proper manipulation of one or the other controller will straighten the bridge. Usually, limit switches are provided for automatically disconnecting the leading motor in case the skewing of the bridge exceeds the safe limit.

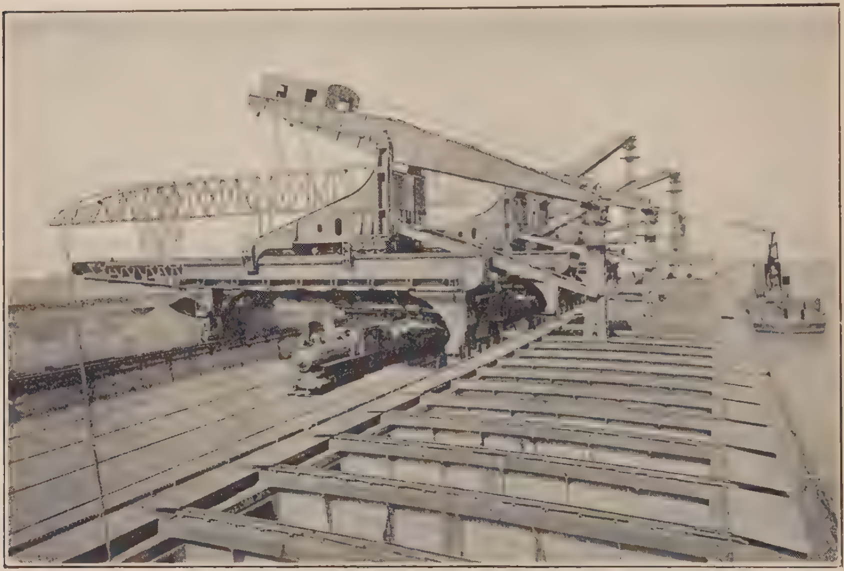
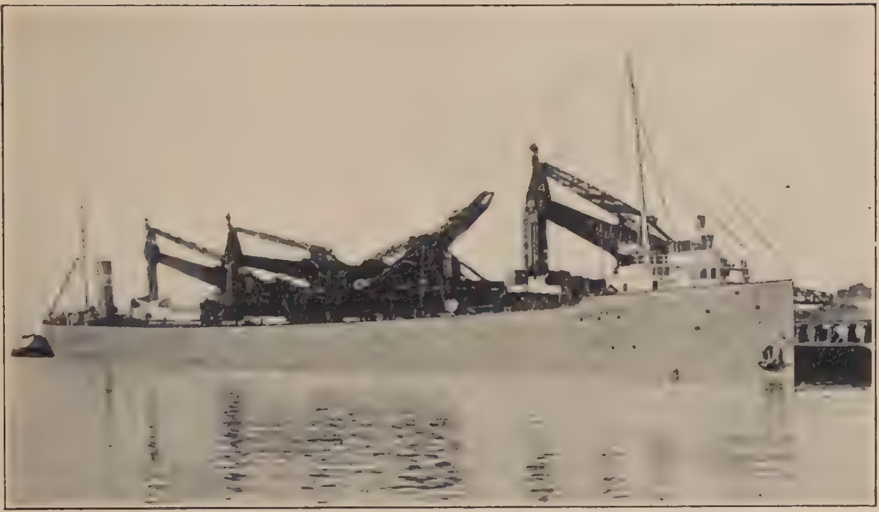


FIG. 384. Hulett Unloaders with Magnet Switch Control

SUMMARY OF CHAPTER XXXII

During the navigable periods on the Great Lakes ore is shipped from the Lake Superior region to eastern Lake ports and coal shipped back. Ore is loaded from



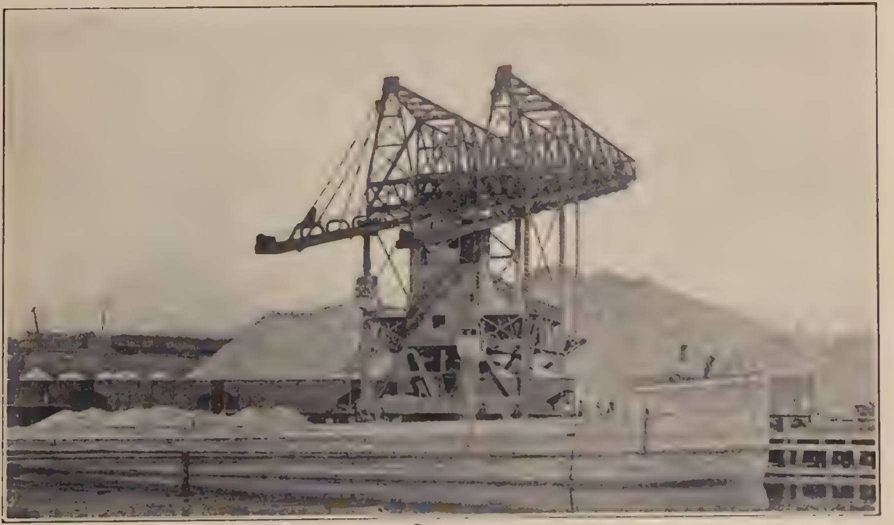


Fig. 385. 15-Ton Hulett Unloaders and Ore Bridge. Each Unloader Has an Aggregate of 810 hp. of Motors

bins by means of chutes into ore boats at the Lake Superior ports, and removed by means of ore bridges to cars for transportation to the blast furnaces, or placed temporarily in stock piles. For the return voyage car dumpers load the boats with coal, which is removed by unloading bridges at the Lake Superior ports.

The ore or coal bridge consists of a structural steel span supported on two piers. The supports are mounted on tracks and moved by electric motors. On a runway on the bridge is a trolley which moves back and forth, carrying the hoisting mechanism and usually the operator's cab. By means of the bridge and trolley motion a position is reached directly over the hatchway of the boat, when the clam shell bucket is lowered by the hoisting mechanism and a load of ore lifted and transported to a bin or graded stock pile.

The hoist contains two drums, on which are wound the shell line and closing line, the former primarily for lifting and lowering, the latter for opening and closing, the bucket, although the movements of both are combined in operation.

Either a-c. or d-c. motors may be used. The trolley usually has two motors, the armatures being connected in parallel and the fields in series. The bridge piers are moved by two motors, controllers governing the motion of each to keep their movements uniform, with limit switches to prevent skewing beyond safe limits.

CHAPTER XXXIII

COKE

Beehive coke ovens versus by-product coke plants—pusher, leveler, and door machine—operation and system of control.

EVERY American should be interested in the conservation of our national resources and the making in America of dyes and other chemicals, which were formerly purchased from Germany. For years this country wasted perhaps the most valuable part of the coal in the manufacture of coke. Coke is produced from coal by the action of heat. The process drives off the tar and volatile matter, leaving a hard gray substance known as coke. Until recently the process was carried on in this country in what are known as "beehive coke ovens." This process produced only coke, and wasted the by-products.

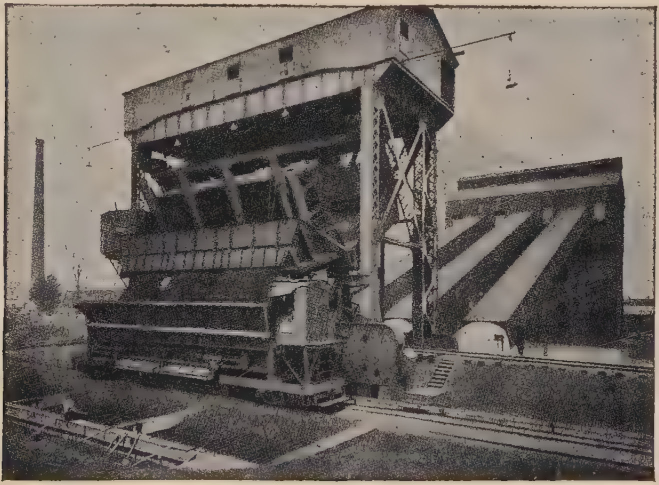


FIG. 386. Car Dumper and Coal Handling Equipment

During the past ten years a large number of plants have been built which conserve the by-products and are often referred to as by-product coke and gas oven plants. These plants eliminate a great deal of the dust and fumes which originally ruined the country for miles around and, while there is still dust in some of the operations, there is no nuisance or damage to the surrounding country. This dust consists largely of coke breeze, which is a very fine coke dust. There is also dust in and about the crushers and conveying apparatus. It is therefore necessary to protect all control apparatus from this dust to reduce the maintenance cost and insure reliable operation. Many of the controller panels are enclosed in cabinets provided with felt packing around the door. Examples of these cabinets are shown in Figs. 387 and 388.

The control applications to a by-product coke plant can best be described by taking up the process of manufacturing coke from the time the coal is received at the plant until the coke is ready for shipment.

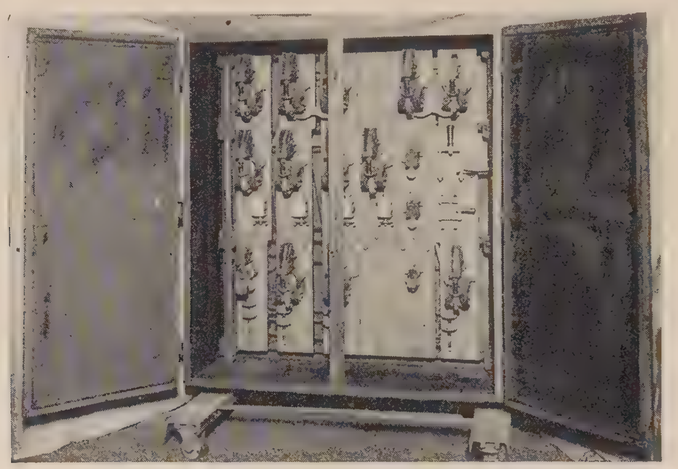


Fig. 387. Contactor Panel for Pusher Ram Controller
Diagram of connections shown in Fig. 391

The method of handling the coal from the cars or barges to the receiving bins depends upon the locality and method of receiving the coal. Where the coal is shipped by rail, the car is often elevated to a height of 40 or 50 ft. and emptied directly into the receiving bin. In other cases the coal is emptied into a track hopper and conveyed by belts to the bins. This latter process is shown in Fig. 386. When the coal is received by barges, a regular unloader may be used or some form of hoist with clam-shell bucket. Where the coal is stored in the open, a coal bridge is required.

Coal is conveyed from the receiving bins to the breakers and crushers. These crushers consist of hammer mills or rolls driven by constant speed motors, the controller being of a plain rheostatic type for direct-current motors or slip-ring motors. Where squirrel-cage motors are used standard autostarters are applied. The starting requirements for these rolls are sometimes quite severe and care should be taken in applying squirrel-cage induction motors to see that sufficient starting torque is available.

The control equipment for coal handling machinery is often combined into one large board located in a dust proof building. The master controllers, which are usually push buttons, are located close to the individual motors, so that the attendant must be close to the motor when it starts. This arrangement makes it necessary for the operator in charge of starting the motors, to walk the entire length of different conveyors and inspect them together with the driving machinery before starting the motors. Safety stop buttons are located at convenient intervals along the entire

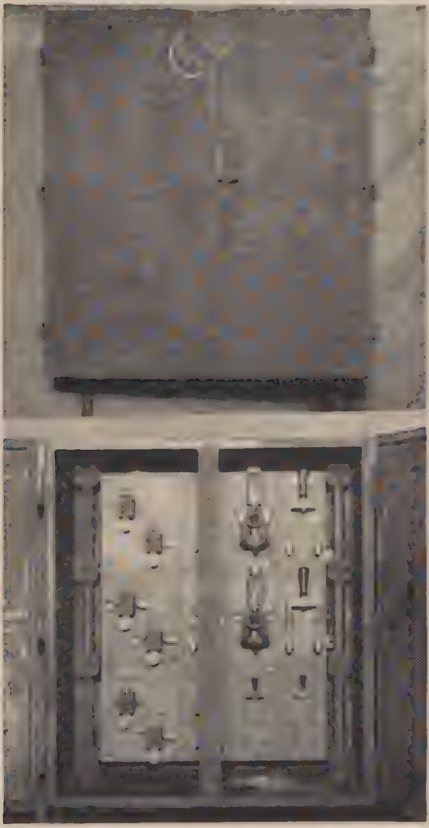


FIG. 388. Protective Panel for Pusher Ram

Doors open and closed. Diagram of connections shown in Fig. 391

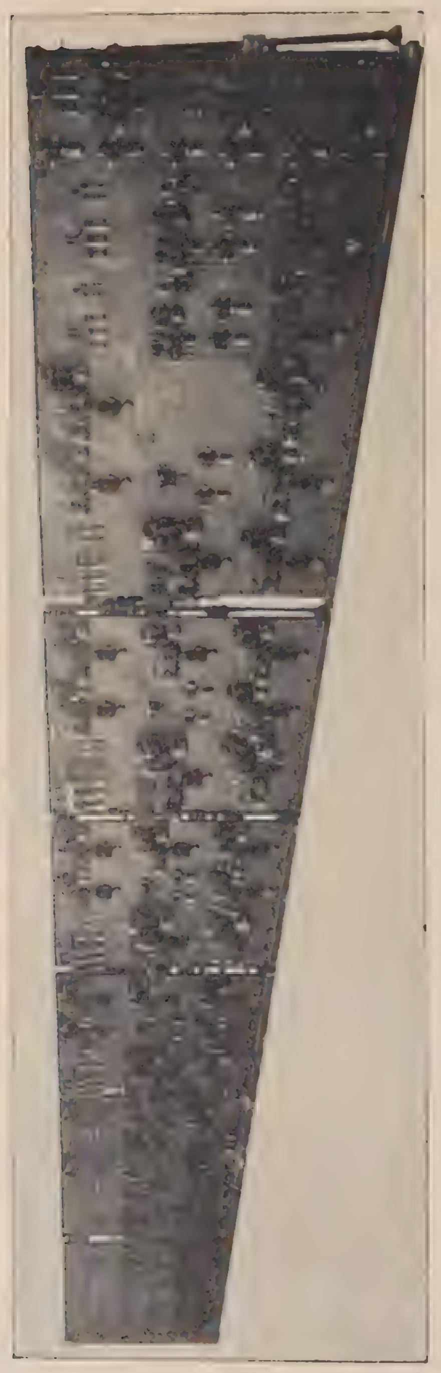
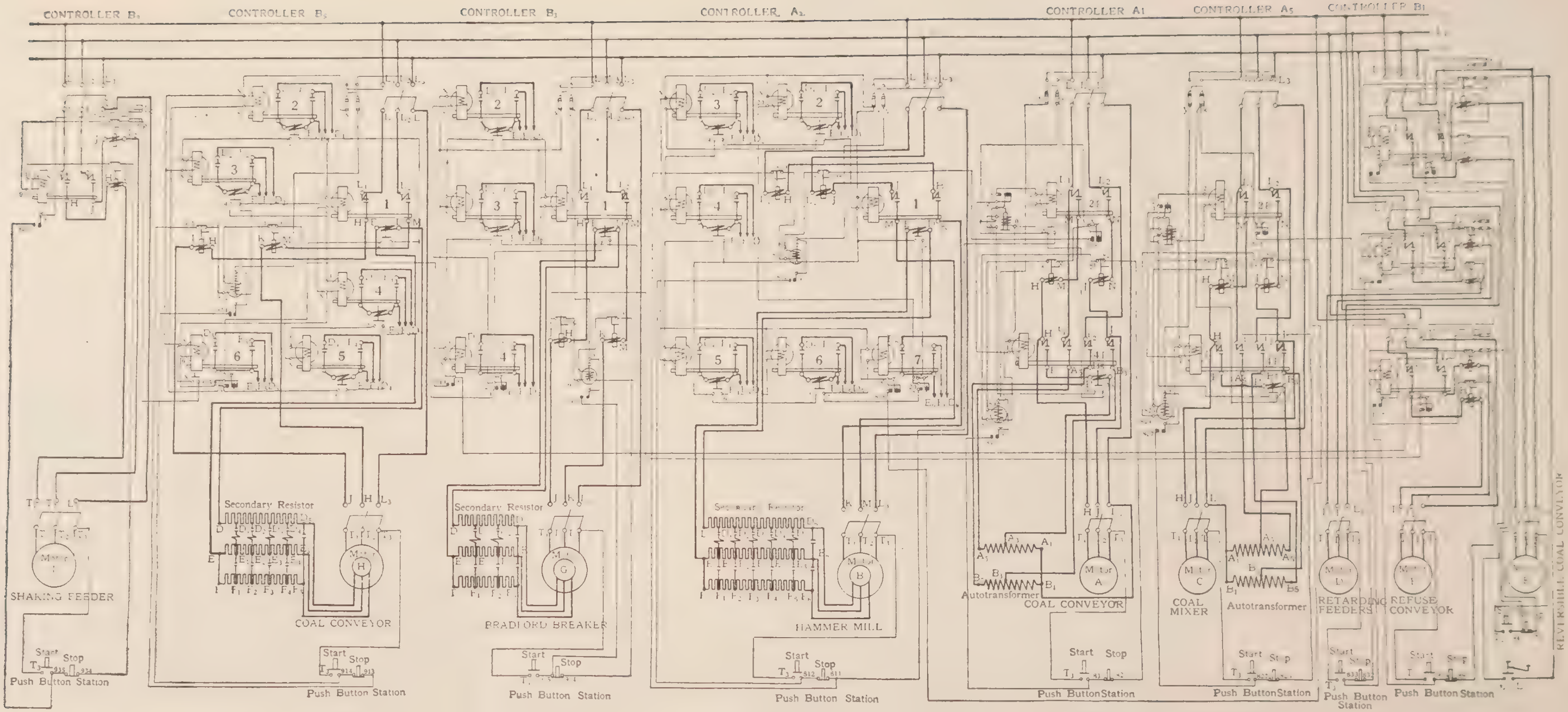


Fig. 389. Interlocking Control Panels for the Coal Handling Machinery Corresponding to the diagram shown in Fig. 392



SEQUENCE OF CONTACTORS CONTROLLER B_5

Con	Run					
1	○	○	○	○	○	○
2		○	○	○	○	
3			○	○	○	
4				○	○	
5					○	
6						○

SEQUENCE OF CONTACTORS CONTROLLER B_3

Con	Run			
1	○	○	○	○
2		○	○	
3			○	
4				○

SEQUENCE OF CONTACTORS CONTROLLER A_3

Con	Run						
1	○	○	○	○	○	○	○
2		○	○	○	○	○	
3			○	○	○	○	
4				○	○	○	
5					○	○	
6						○	
7							○

SCHEME OF MAIN CONNECTIONS CONTROLLERS A1 and A5 From 3 Phase Line

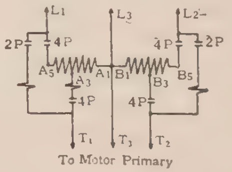


FIG. 392. Coal Handling Control

The entire motor and control equipment is alternating current. Part of the motors are squirrel-cage and part of the slip-ring type. Each controller is of the contactor type and self-contained, provided with a push button for starting and another button for stopping. The controllers are interlocked so that motor *A* must be started first, then motors *B*, *C*, etc. If motor *C* is stopped, motors *D*, *E*, *F*, *G*, *H* and *I* will also stop automatically. It will then be necessary to start motor *C* before the others can be started. The operating of any one of the stop buttons stops all of the motors ahead of that control. This diagram has been simplified by omitting all duplicate equipment. The actual control system provides for additional motors

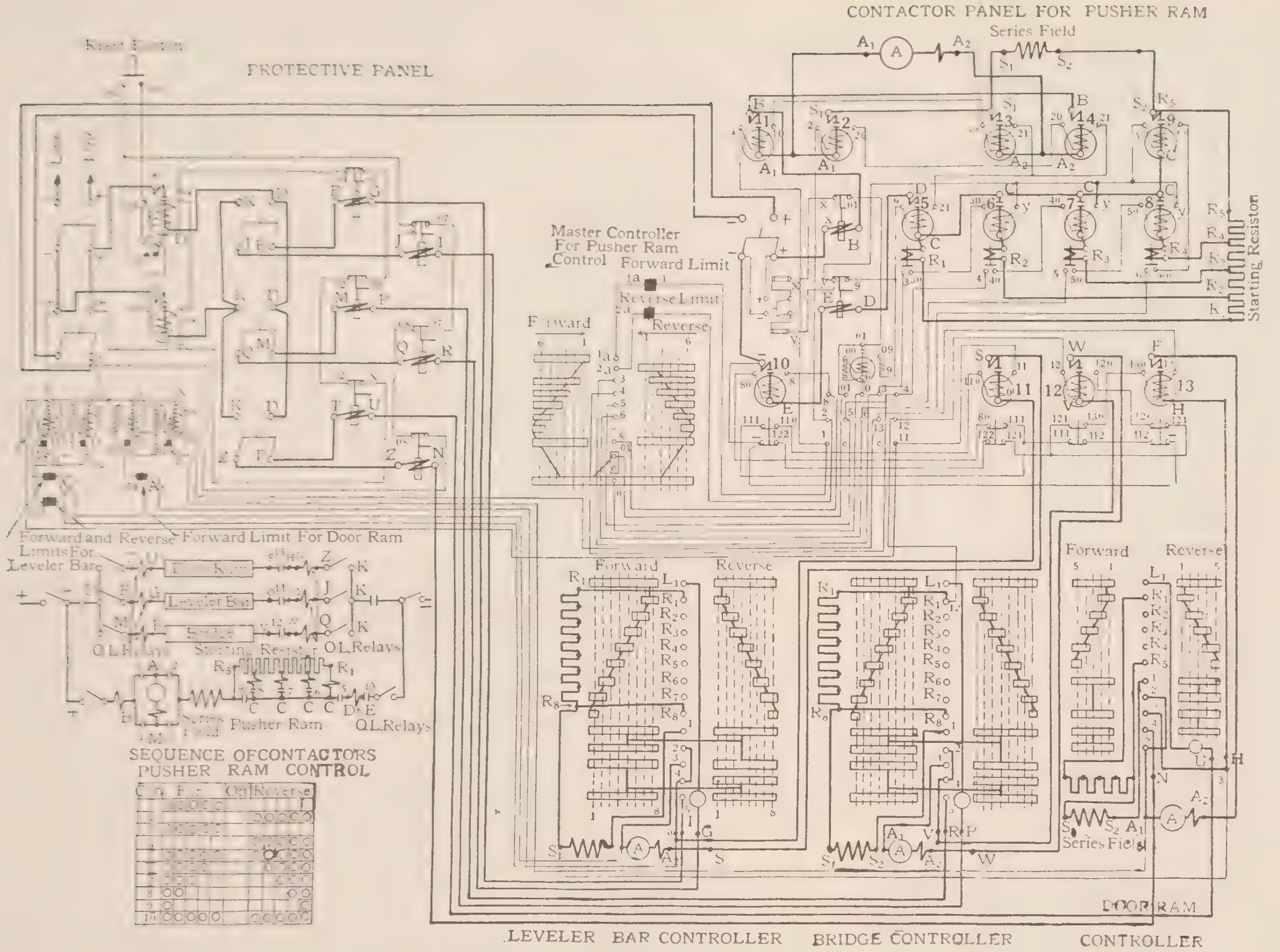


FIG. 391. Pusher, Leveler and Door Machine Control

The panel at the left is used for disconnecting and protective purposes. It has an overload relay in each side of each motor circuit connected to the drum controllers. The two magnetic contactors are used for opening either side of the line in case any of the overload relays operate. The four small contactors on the lower left hand side of the diagram are used in connection with the limit switches for opening the motor circuits for interlocking between the controllers. In the upper right hand corner of the diagram is the main control panel for the pusher ram. This consists of four reversing switches, four accelerating switches, one line contactor, and one interlocking contactor. In addition, there are three interlocking contactors, one for each drum controller. The four interlocking contactors are so arranged that only one controller can be operated at a time. The magnet contactor control is operated from the six point drum type master switch. The schematic diagram shows the main connections. The sequence table is for the pusher ram control length of the conveyor galleries so that the machinery can be stopped if anything goes wrong or an accident should occur. The coal handling control is so interlocked that the machine at the delivery end of the system must be started first and the other machines in their order up to the receiving end of the system. Should a machine in any part of the system stop, all of the machines back of it are automatically stopped to prevent the loading up or accumulation of material in any part of the system. The remaining machinery on the delivery end continues to operate, thus unloading all of the material in that part of the conveyor system. In some plants a relay is used for stopping the conveyor if the load goes off, due to the breakage of a belt, gear, etc. This relay operates to open the contact if the load on the motor falls below a fixed value.

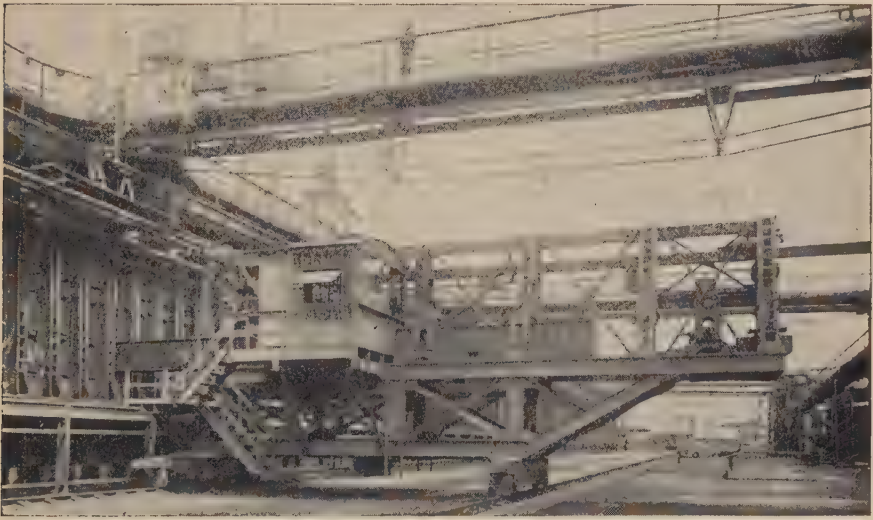


FIG. 390. Combined Pusher, Leveler and Door Machine

In some instances as many as twenty motors have been interlocked on a system of this kind. As a rule, however, they are divided into two or more groups, each group conveying the material to a storage or mixer bin. Lights or other signal devices are used so that when one group of conveyor motors is started up the operator on the second group is signaled automatically to start up his group.

The ovens are arranged in batteries and are opened at both ends. Each oven is about 8 inches wide by 10 feet high and 40 feet long and has a capacity of from 11 to 16 net tons of pulverized coal. Coal is charged into the ovens by a larry car having four hoppers. This car conveys the coal from the storage above the ovens to the ovens themselves. These cars are generally operated by direct-current motors with the ordinary rheostatic reversing drum controllers. The current is collected and returned to the line from two collector shoes operating on collector bars at the side of the track.

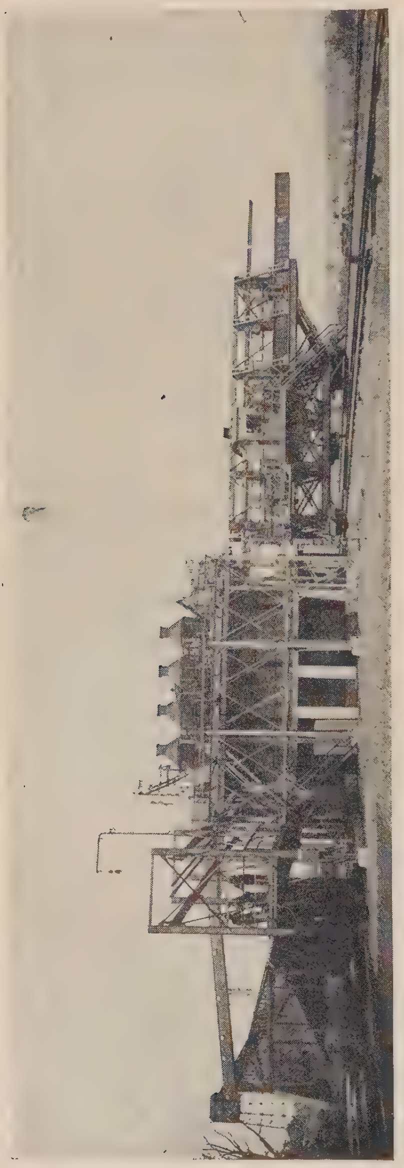


FIG. 393. End of Oven Battery Showing Larry Car, Quenching Car and Pusher Machine

A door machine is provided on each side of the oven. On one side this door machine is combined with a leveling bar and pushing machine, as shown in Fig. 390. On the other side of the oven the door machine is combined with a coke guide through which the coke is forced from the oven into the quenching car. This arrangement is shown in Figs. 393 and 395.

After an oven has been emptied, the doors at each end of the oven are placed in position by the door machines and then sealed with clay to make them air-tight. A small opening is provided in the top of one of the doors for the leveling bar which levels off the coal discharged into the oven by the larry car. After the oven has been completely charged this small opening is closed and sealed. The coking process requires from 14 to 22 hours. When the coke is ready for removal from the oven the door on the one side removed, the coke guide is placed opposite the opening and the quenching car is placed opposite the coke guide. The pushing bar is inserted from the opposite side and the coke forced out through the chute into the quenching car. This is shown in Figs. 390, 393 and 395.

The control for the combined pusher, leveler, and door machine is shown in Fig. 391. The various operations are often interlocked to insure safety in handling the coke and in the movement of the machine. The controllers are of the usual rheostatic reversing type. Both drum controllers and magnetic contactor panels are used, depending upon the size of the motor and the work to be done. Limit switches are provided to prevent over-travel for the machines which have positive limits of travel. The quenching car is moved by a 20-ton electric locomotive which takes it to the quenching station where water is discharged on the coke in the car to reduce its temperature so that it can be handled readily. Fig. 394 shows a load of coke being quenched at the quenching station.

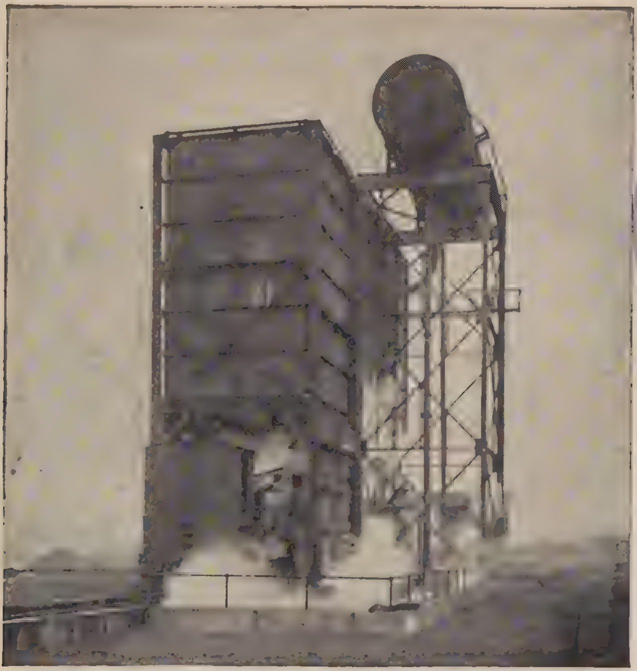


FIG. 394. Coke Quenching Station

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The locomotive then conveys the coke to the coke wharf, Fig. 395, where the coke is discharged and allowed to cool still further. From here it is fed onto belt conveyors by a rotary feeder and conveyed to a screen which separates the coke from the coke breeze or dust. The electrical apparatus which operates the feeding conveyor and screen is subject to a great deal of coke dust and must be carefully protected. The control apparatus is usually the ordinary rheostatic type; either alternating-current or direct-current motors may be used, the former being preferable on account of having fewer moving parts.

The gas and fumes which are distilled from the coal during the formation of coke are conveyed to various tanks and stills where the by-products are separated and refined. The electrical apparatus for this part of the equipment has no unusual features. During the heating process when the coal is changed to coke, in a well-known type of oven, the direction of the gas through the ovens and flues is changed about every thirty minutes. This change is usually taken care of by clock-work which operates the motors that change the dampers.

FIG. 395. Coke Wharf and Coke Quenching Car

Alternating-current motors are preferable for all conveyors, crushers, damper regulators and screens. These motors have fewer moving parts than a direct-current motor and are less likely to be affected by the dust. Direct-current motors are preferable for traction purposes, also for the pusher, leveler and door machine, and for the unloading machines, either a car dumper or a hoist. All of the motors and controllers in a coke plant are subject to a great deal of dust and fumes. Special treatment should be given the exposed windings of motors and in some cases artificial ventilation is provided so that clean air can be taken from the outside and passed through the electrical apparatus. Little or no speed variation is required on most of the apparatus. Where speed regulation is required, direct-current motors are recommended. An important feature in the control equipment is the proper interlocking of groups of controllers to prevent accident.

SUMMARY OF CHAPTER XXXIII

When coal is heated the tar and volatile matters are driven off, leaving a hard gray substance known as coke. The tar and volatile matters are wasted in the beehive type of coke oven, but in modern by-product coke plants are recovered and utilized. The dust and fumes are also confined to the plants, preventing the surrounding country from contamination, but electrical equipment must be enclosed and the windings treated.

The coal when received is unloaded into receiving bins, from which it is conveyed as needed to breakers and crushers. A conveyor system then carries it to storage or mixer bins over the ovens, into which it is charged by hopper or larry cars. In a combined pusher, leveler, and door machine the leveling bar levels the charge, the oven is opened after the heating operation by the door machine, and the charge emptied by the pusher bar into the quenching car, through the coke guide placed temporarily in the door opening. The quenching car is moved to the quenching station, where water is applied to reduce the temperature of the coke for further handling. After conveyance to a screen, the coke breeze or dust is separated from the coke proper. The distilled by-products are conveyed to tanks and stills for separation and refining.

For dust-producing operatings a-c. motors are preferable; for traction purposes, also for the pusher, leveler, and door machine, d-c. motors are preferred. Controllers are mounted in dustproof enclosing cabinets or control rooms, and motor and other windings are specially treated to protect them from fumes and dust. In some cases the motors are artificially ventilated to ensure the circulation of clean air. The control schemes are interlocked to ensure the proper sequence and to prevent interference of operations and resulting accidents.

CHAPTER XXXIV

ELEVATORS, RHEOSTATIC CONTROL

Elevators—electric versus hydraulic systems—rheostatic system of control—direct-current installations—alternating-current installations—two-speed alternating-current motor.

UNTIL about 1904 the electric elevator was used for small installations. The large office buildings and hotels used hydraulic power to operate their elevators. The hydraulic elevator has the disadvantage that it is inherently a constant power machine, as it takes the same amount of water whether the car is operated empty or loaded; and it is not feasible to overbalance the car on account of the fact that the hydraulic elevator is a single-acting machine and part of the car weight must be left unbalanced in order to circulate the water when the car is descending. There is another disadvantage; every hydraulic installation requires a power plant, consisting of pumps, tanks, regulating apparatus, and a considerable amount of expensive piping. Many large elevator installations still use hydraulic elevators, but the improvement in electric elevators has extended their use so that today they are the preferred type of elevator for all installations. In fact, some of the highest buildings could not have been successfully equipped with hydraulic elevators, on account of the length of car travel.

The electric elevator has less investment and maintenance cost than the hydraulic, due to the elimination of the power plant. It is also more economical to operate because the power used is proportional to the load.

Electric elevators are used for a wide range of service conditions. The simplest form of elevator mechanism consists of a driving sheave operated from a countershaft by suitable belting. The countershaft is run continuously by an electric motor and the elevator is operated up or down by shifting the belts from the loose pulley to either the forward or reverse operating pulley. The elevator is brought to rest by means of a mechanical brake connected to the belt shifting mechanism. These elevators usually lift from 1000 to 2000 pounds at 50 feet per minute. This type is no longer installed.

The next advance step is made by belting the motor to the drum with a single belt and securing up or down operation of the elevator car by

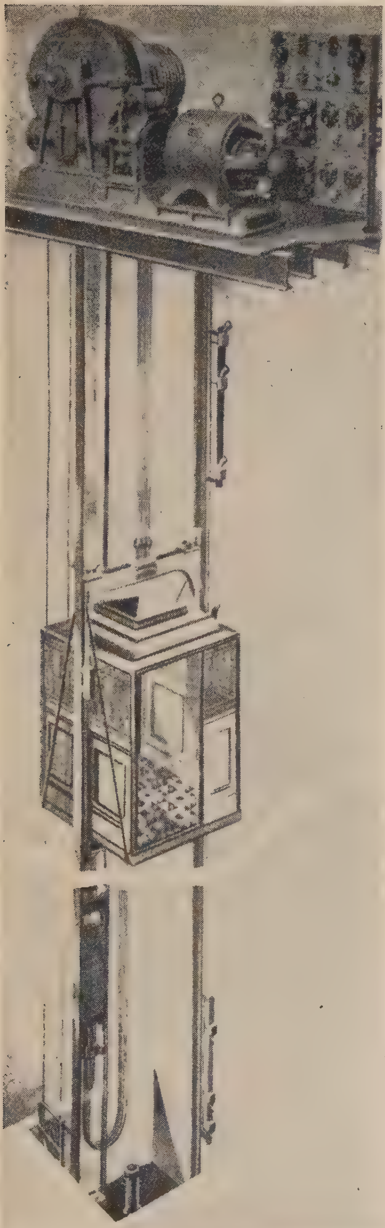

Fig. 396. Complete Elevator Equipment

The rope passes from the top of the car around the traction drum on the hoisting engine and thence to a counterweight running on a pair of guides at the rear of the hatchway. Another set of cables runs from the bottom of the counterweight to the bottom of the car. These cables are used for counterbalancing purposes only and do not carry any of the load. The controller is shown at the right of the motor, both motor and control being located above the hatchway. Along the side of the runway for the car at both the top and bottom are shown three limit switches for bringing the car to rest automatically at either limit of travel. On the bottom of the hatchway is shown an oil buffer to stop the car in case it should creep beyond the usual limits of travel.

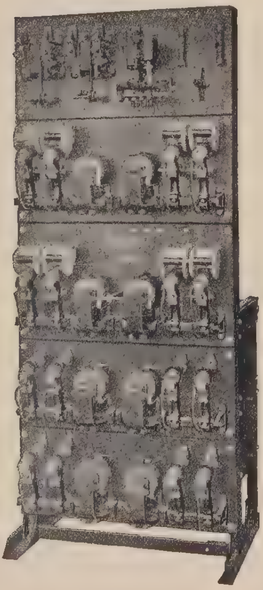

Fig. 397. A-c. Full Magnetic Two-speed Elevator Controller

This controller is suitable for installations whose car speeds reach 350 feet per minute. It is equipped with slow-down feature running the motor in either the forward or reverse direction. These two types of machines are used for slow-speed freight service.

A more substantial machine is made by mounting the motor on a common bed plate with the drum and gearing, thus forming a self-contained unit. The gearing consists of either a single wheel with ball bearing end thrusts on the worm for passenger and light freight duty, or a double wheel with right and left worms, for heavy loads. The geared type of machine is used with car speeds of 400 feet per minute and lower speeds.

For large office buildings, hotels, and similar applications, car speeds of from 450 to 600 feet per minute are usual. In place of the winding drum, a grooved wheel is used, the drive depending upon the friction between the rope and the wheel. This type is the one in present general use and is known as a "traction elevator machine." The rope connection between the car and the machine may be arranged for 1 : 1 gearing, in which case, the car travels at the same speed as the circumference of the driving sheave. Another form has a rope connection which gives a car speed equal to one half the peripheral speed of the driving sheave. This is known as "2 : 1 traction." In some cases, the driving sheave is mounted directly on the motor shaft and a slow-speed motor is used, operating from 30 to 60 revolutions per minute. Another form has herring-bone or worm gears between the motor shaft and the driving sheave. This is known as a "gear type traction machine."

For freight service, where the loads are heavy and high speeds are not necessary, a drum machine having a combination of worm and spur gearing is used. A pinion is mounted on the worm wheel shaft and meshes with an internal gear bolted to the end of the drum. This gives extra lifting power at a slower speed, but the spur gearing causes the machine to run less smoothly than a straight worm-gear drive.

The smooth running of the car is affected by a number of conditions. The car travels on two guide rails mounted vertically in the shaft. Any irregularities in these rails will be felt in the car. The guide shoes mounted on the car must have flexibility, in order to take up the lost motion and, at the same time, not cause undue friction. A poor adjustment of these guide shoes will often cause a swaying or rattling of the car. Improperly adjusted shoes or gritty rails may cause a disagreeable scraping sound. Gearing when used should be very smooth in operation and have little or no back lash. The effect of a rough worm wheel or bad end thrust bearings can readily be felt by a passenger in the car. Defects of this kind cause tremors or vibrations which are very disagreeable.

A friction brake is used to effect the final stop and to hold the car

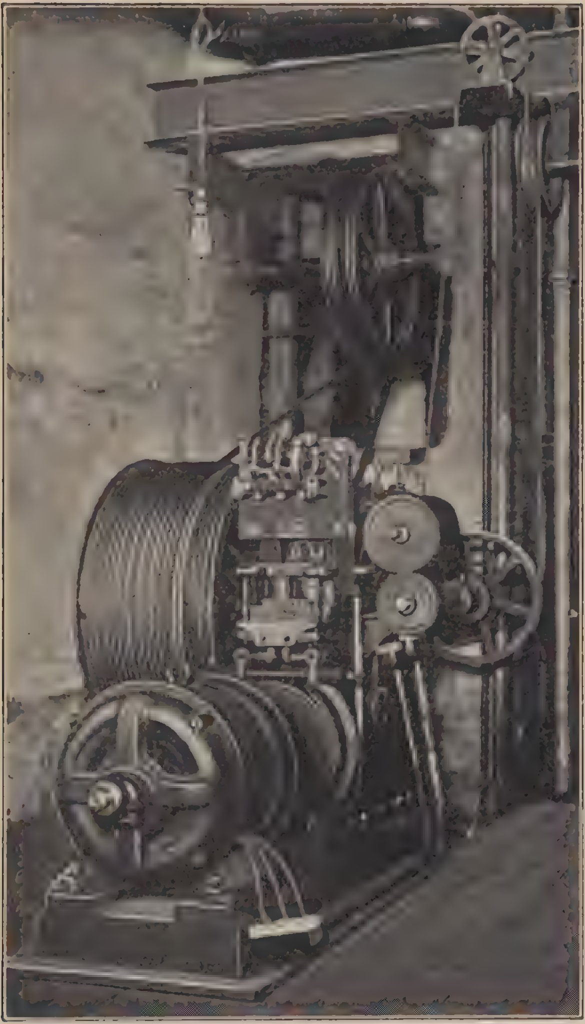

FIG. 398. A Worm-gear Drum-type Elevator Machine

Located in the basement and set back from the hatchway so that the car and counterweight ropes pass around the two idler sheaves shown. They are technically known as vibrating sheaves because they travel to the right or left along their shaft as the rope winds on or off the drum. To the right of the machine is shown a rope wheel, which is operated from the car by means of a lever or wheel. This rope wheel operates the reverse switch back of the large gear, which connects the motor to the line through the magnetic contactor shown next to the drum. The motor is of the squirrel-cage induction-type, which can be connected directly to the line. The friction brake is located between the motor and the worm gearing, and consists of a wheel with two shoes, which are pressed against the wheel by coil springs and released by the polyphase brake magnet shown above the brake securely at the landings. Considerable skill is required in designing this brake to make its action soft and gradual.

The acceleration and retardation or deceleration of the car depend largely upon the controller, although it is essential that the electric motors have proper characteristics. The passengers notice the rate of change of acceleration more than the acceleration itself. Therefore a controller should be so designed that the rate of acceleration will not be changed abruptly, either in starting or stopping the car.

Usually the motor is started with resistance in the armature circuit. This resistance is short-circuited in steps, finally bringing the motor to full speed. The steps of resistance have a finite value and therefore each step represents a change in the rate of acceleration which has a tendency to be abrupt. The design of the motor and control should be so adjusted that these abrupt changes in the torque of the motor will be minimized. This adjustment is improved by having a motor that does not respond too quickly to a change in impressed voltage, and by providing a considerable number of steps in the starting resistance. The change in the amount of this resistance is usually controlled automatically, in which case the switch in the car determines the amount of resistance which may be cut out, but the automatic arrangement in the controller fixes the rate at which the resistance is short-circuited.

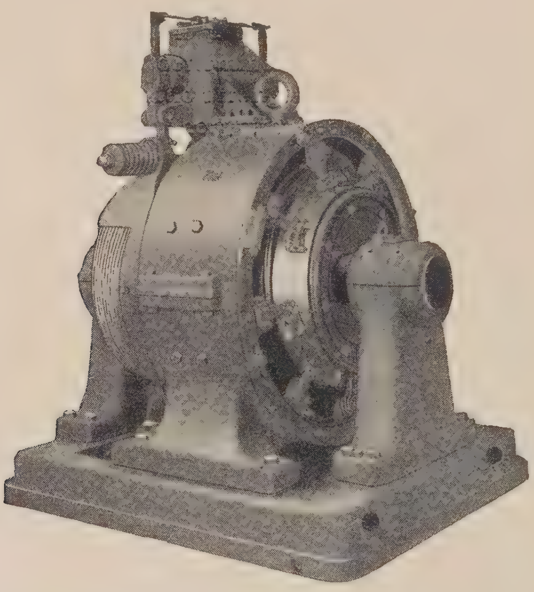

FIG. 399. Gearless Traction Elevator Motor 40 Hp., 230 Volt, 65 R.p.m.

Where an adjustable speed motor is used, the changes in field strength must be effected gradually. This is to a certain extent an inherent characteristic of the motor. In some cases, however, it must be assisted by automatic means embodied in the controller.

Counterbalances are used having sufficient weight to compensate for the weight of the car and a part of the load. The object of this counterbalance is to reduce the work done by the motor in moving the car from one landing to another. The counterweight is connected to the winding drum in the reverse direction from the hoisting ropes, so that when the hoisting rope is wound up, the counterbalance rope is unwound and vice versa. If the load in the car is such as to just equal the counterbalance, the motor overcomes friction only. If the car is at the top of the runway and a load in excess of the counterbalance is placed in the car, the car

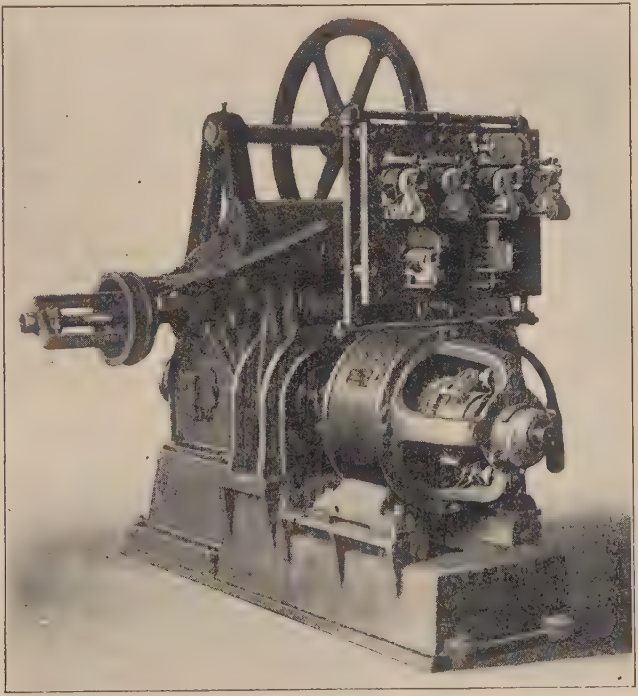

FIG. 400. Direct-current Motor Driving an Elevator Equipment

The controller is mounted directly above the motor and is used in connection with a reverse switch which is mounted above the brake and operated by the rack and gear shown on the left. The device projecting from the machine on an extension of the drum shaft is the stop-motion gearing, for returning the controller to the off position and applying the friction brake automatically at either limit of travel drives the winding drum, due to its excess weight, and causes the motor to operate as a generator. The same condition is obtained if the car is at the bottom of the runway, and starts up with a very light load. The counterbalance in this case being heavier than the car, drives the motor as a generator.

The elevator is "overbalanced" to limit the maximum current drawn from the power line. If the overbalance is equal to half of the maximum load the car is required to lift, it is obvious that the motor need be only half the size that would be required if no overbalance were used. A somewhat larger motor is generally selected and the overbalance reduced to equal half of the average load, which is from 30 to 40 per cent of the maximum load.

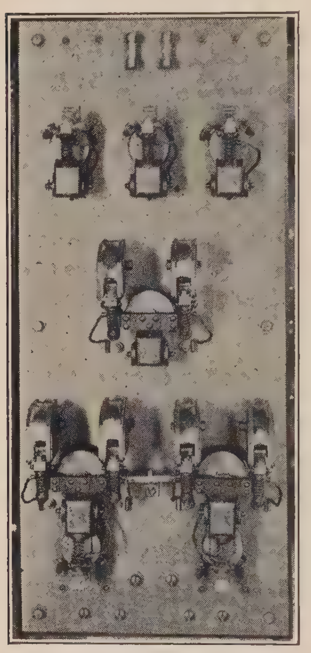

FIG. 401. Single Speed Controller for Direct Current Elevator

The over-counterbalance of the car weight causes the motor to operate part of the time as a motor and part of the time as a generator. This generator action may occur either with the car ascending or descending, depending upon the loading. It complicates the controller problem materially. If the controller is adjusted to accelerate with the maximum positive load on the motor, it will have a tendency to jerk the car when accelerating with the maximum negative load. In stopping a car, the same conditions hold, so that a great deal of care must be exercised where high-speed cars are used. If the speed of a car is 100 to 150 feet per minute, the change in rate of acceleration between positive and negative values of loading is not very pronounced. If, however, the car speed is 600 feet per minute a marked difference may be noticed.

An elevator car has a limit of travel in either direction. Downward, it is the bottom of the pit, and upward, the sheave beams. It is therefore very important that the car be brought to a positive stop at the top and bottom landings. As a matter of safety, both stops must be independent of the operator. There are various ways of doing this. Where the ropes are wound on a drum, a mechanical attachment known as the "stop motion gearing," is provided, usually on an extension on the drum shaft. This gearing operates the controllers and sets the brake at either limit of travel. For high-speed cars, several slow-down steps are provided before the final stop is made. As the speed of the car decreases, fewer slow-down steps are required, and for slow-speed passenger and freight cars, only one step is used. This method is known as a "machine limit stop" because it is driven by the winding machine.

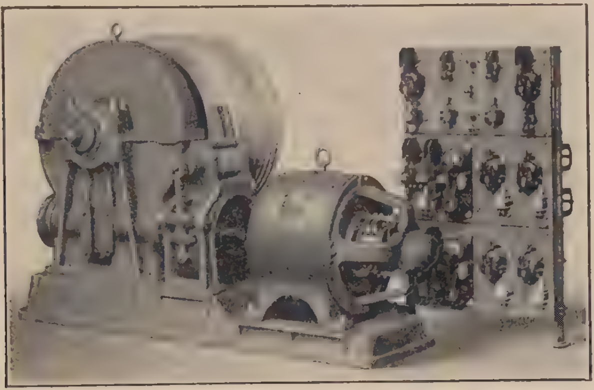

FIG. 402. Geared Traction-type Elevator Machine

The reverse switches, as well as the remainder of the control, are operated electrically. There is no stop-motion gearing on this machine, as this form of limit stop is not used on traction-type machines

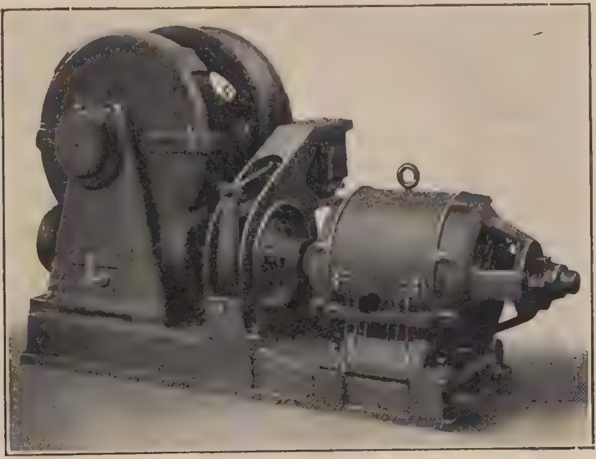

FIG. 403. A Worm-gear Machine

Operated by a two-speed wound secondary-induction motor. The friction brake is released by an alternating-current magnet and the controller, shown in Fig. 409, is actuated entirely by magnets

Another device, known as the "hatchway limit stop," consists of one or more small switches placed in the hatchway and arranged at either operated by the car in passing. These switches are arranged at either limit of travel and can give both slow-down and stop when required. For traction machines, where the rope is not positively attached to the machine, as in a winding drum, the machine limit stops are not safe or satisfactory, so that hatchway limit stops are used; a limit switch attached to the car is also used.

A traction drive for an elevator car is inherently safer than a drum, because the car or counterweight, on reaching the bottom of its travel, takes most of the tension off the ropes and allows them to slip on the driving sheaves, preventing a further movement of either car or counterweight. Oil buffers are provided for cushioning the impact at the limits of travel.

The successful operation of an elevator depends largely upon the control equipment, including the magnet brake. Every direct-current controller should have the following features:

1. A line switch to disconnect the motor from the electric circuit. This switch may be operated every time the car is operated, or it may remain closed normally and be opened only by some of the safety devices or when the line voltage fails.
2. A reversing switch to change the direction of rotation of the motor. (Sometimes several switches are used combining 1 and 2.)
3. An accelerating device for gradually short-circuiting the starting resistance. Where a variable speed direct-current motor is used, this device must also gradually weaken the motor field to attain the maximum speed of the elevator car.
4. A dynamic brake for slowing down the car when the elevator is brought to rest. This device is sometimes omitted in slow-speed freight service.
5. A mechanical brake for stopping the elevator car and holding it securely at the landing.
6. A top and bottom limit stop for bringing the car gradually to rest at either limit of travel, independently of the operator.
7. A controlling device in the car for operating the elevator. This may consist of a master switch or a mechanical device such as a rope or lever.
8. A slack cable device (on drum machine only) for stopping the motor in case the car or counter-weight should become obstructed in its travel, causing the ropes to lose their tension. This does not apply to the traction type of elevators.
9. An over-speed switch for disconnecting the motor from the line at the time that the car safety device operates to grip the guide rails. In some forms of machine a slack cable switch is depended upon to perform this operation.

10. Overload protection for the motor. This frequency consists of fuses, although sometimes overload and no-voltage circuit breakers are used, or a circuit breaker relay with magnet control.
11. An emergency switch on the car to enable the operator to stop the car in case his regular controlling device becomes disarranged.

In addition to the above, high-speed passenger elevators must have the following control feature:

12. One or more positive slow-speed notches. It is necessary to have a slow-speed notch to enable the operator to stop his car accurately at the landings. This slow speed is also necessary to bring the car to rest properly at either limit of travel. Where the speed of the car exceeds 400 feet per minute, several slow speeds are desirable in order to obtain efficient operation of the elevator.

For high-speed elevators, it is customary to provide oil-buffers under the car and counter-weights. In addition to the controller proper, it is desirable to provide contacts on the hatchway doors or gates which will prevent car operation until the gate is closed. Sometimes the car itself is equipped with a gate having one of these contacts.

The above functions of the electric control are accomplished in a variety of ways, the devices used depending upon the characteristics of the electric motor.

DIRECT-CURRENT ELEVATORS

The first successful electric elevators were operated by compound-wound direct-current motors. These motors had a fixed shunt field; the compound winding was cut out after starting so that the motor operated as a shunt motor at full speed. This design gave a good starting torque, together with good speed regulation after full speed was reached. In the control scheme, a reversing drum controller was operated first, being following immediately by the closing of the line switch; next a resistance arm was released, moving a brush over a series of contacts which short-circuited the starting resistance and afterwards the series turns on the motor field. The resistance arm was raised by a series-wound solenoid and retarded by a dashpot. This form of controller with various mechanical modifications, is used successfully today for slow-speed passenger and freight service.

The first developments were improvements in the method of cutting out the starting resistance. Some controllers used a shunt coil connected across the motor terminals and actuated by the counter e.m.f. of the motor for moving the resistance arm. The same arrangement is now used, except that the resistance is short-circuited by individual contactors actuated by the counter e.m.f. of the motor and the dashpot is omitted. Other arrangements were developed for closing these individual resistance switches, depending upon the amount of current taken by the motor. The dashpot method of acceleration has one distinct advantage; namely, the resistance can be proportioned to start the motor under light load, and the accelerating device will continue to reduce this resistance until the car starts even under heavy load, so that it is very seldom that an elevator having this method of acceleration will fail to start. This advantage has caused many manufacturers to retain the use of the dashpot, although there are some troubles inherent in this type of apparatus.

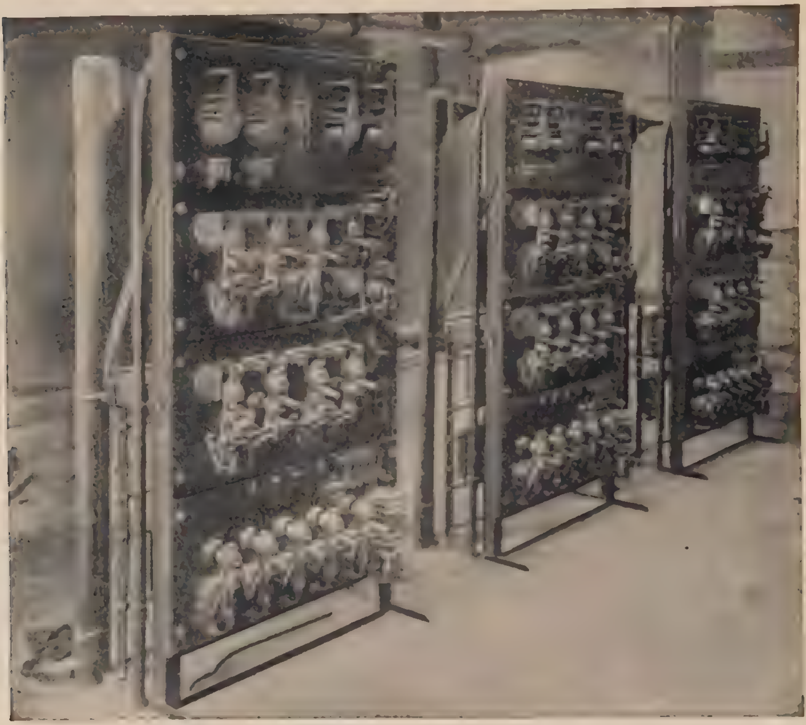

Fig. 404. Three Elevator Controllers

Cars run at 450 feet per minute

Another improvement has been in the line switch and reversing switch. The line switch has been replaced in most controllers by an electrically-operated contactor. Sometimes several of these contactors are used for reversing the motor, while in other cases a mechanical reverse switch in combination with an electrically-operated line contactor is found to be cheaper and just as satisfactory for slow-speed service. A number of other devices for accelerating the motor have been tried, but are seldom used at present. One such device was a rheostat driven by a pilot motor. In addition to the expense of this device, it was too slow in returning to the starting position.

With the development of the shunt motor with a two to one speed adjustment, a new feature was introduced in elevator control. This motor gave two fixed running speeds and made the control of high-speed elevators more positive. Trouble was experienced at first in changing from maximum to minimum speed and vice versa. When the field was reduced, the motor had a tendency to jerk the car and take a heavy current; when the field was strengthened, the motor acted as a generator and reversed the direction of current, tending also to jerk the car. An improved method for controlling the field of the shunt motor is the so-called "fluttering" relay, which strengthens the shunt field on an excess of current, and reduces the field by inserting resistance when the current drops to the proper value.

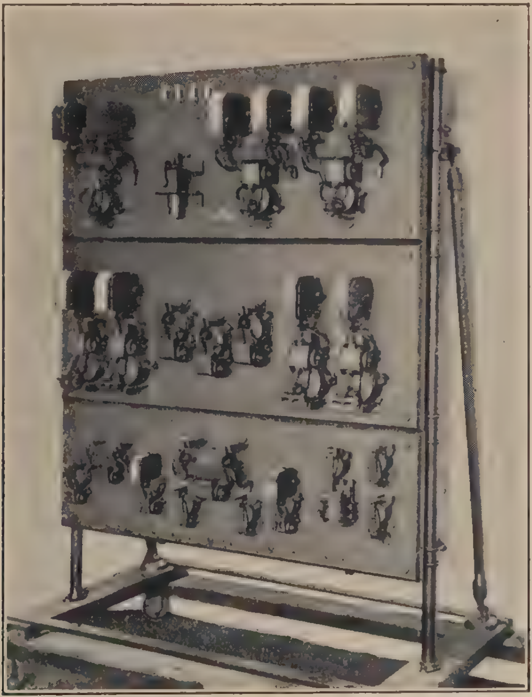

FIG. 405. Rheostatic Control for Traction Elevator

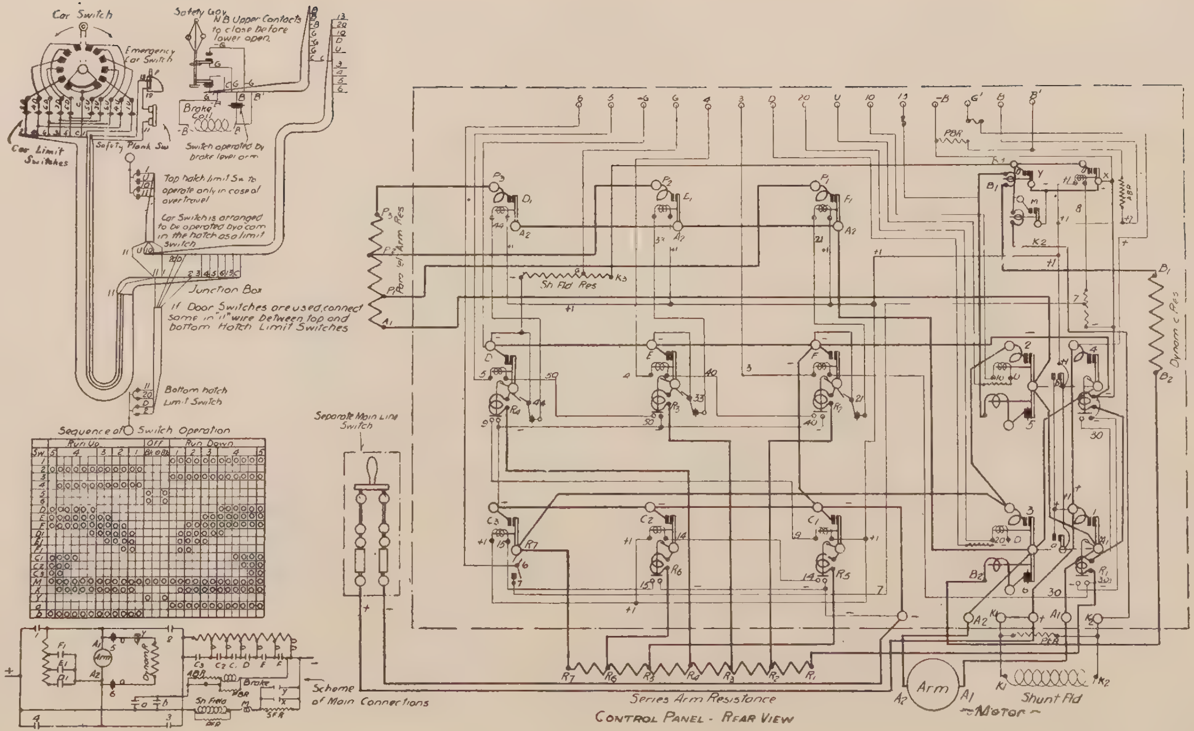
Car Switch
Emergency Car Switch
Car Limit Switches
Safety Plank Sw
Safety Gov
N.B. Upper Contacts to close before lower open.
Brake Coil
Switch operated by brake lever arm
Top hatch limit Sw. to operate only in case of overtravel
Car Switch is arranged to be operated by a cam in the hatch as a limit switch
Junction Box
If Door Switches are used, connect same in "11" wire between top and bottom Hatch Limit Switches
Bottom hatch Limit Switch
Sequence of Switch Operation
Run Up
Off
Run Down
Scheme of Main Connections
Separate Main Line Switch
Arm'ct Arm Res
Sh Fld Res
Dynamic Res
Series Arm Resistance
CONTROL PANEL - REAR VIEW
Arm
Shunt Fld
Motor

FIG. 406. Diagram for Rheostatic Elevator Controller

A further increase in car speeds made it necessary to provide a slower running speed than could be economically obtained by shunt field control. This slow speed is secured by shunting the armature with a resistance at the same time that resistance is inserted in series with the armature, as shown diagrammatically in Fig. 406. The shunt field may also be increased to assist in slowing down. This gives a positive slow speed, even with negative loading, the speed, of course, being faster with a negative load than with a positive load. For high-speed service, several speed points are provided on the master switch so that the speed in making the landing can be adjusted to suit the loading of a car. In stopping, the resistance in shunt with the armature is used for dynamic braking. In addition to the armature shunt resistance, a second or emergency resistance is frequently used, so that should an open circuit occur in either resistor, at least one resistor would be available for dynamic braking. Sometimes both resistors are used each time the master switch is placed in the off position. If a car is descending with the maximum load at

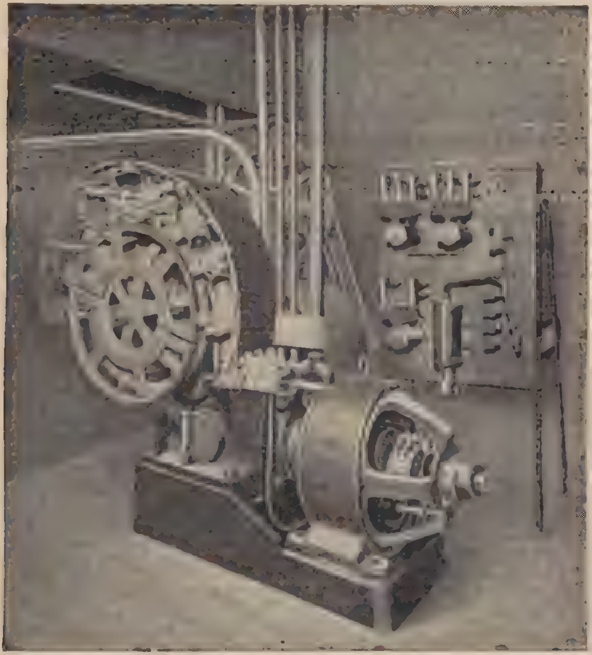

Fig. 407. Electric Elevator Showing the Automatic Switch for Push Button Control

This switch is arranged for calling or sending the elevator to some specific floor by the pushing of the button at the landing full speed and the operator throws the master switch quickly to the off position, the stopping of the car can usually be felt by the passengers. Often a perceptible bump, or sometimes a series of bumps, occurs due to sudden changes in the rate of deceleration. A good operator, however, moves his switch lever gradually so as to give a smooth control. To a certain extent, the same effect is noticeable in the handling of railroad trains, street cars, etc., where the engineer or motorman may jerk his train or car very badly if he is careless in starting or stopping. The skilled operator will bring his car flush with the landing almost every time. It is the abrupt jerking of the car back and forth to make a landing that is disagreeable to the passengers and indicates an unskilled operator.

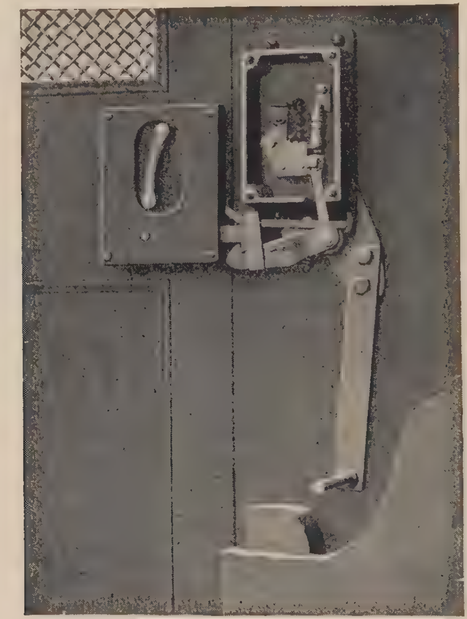

FIG. 408. Door Lock and Contact

This shows a device used for locking the hatchway door when not in use. A cam on the car automatically operates this lock so that the door can be opened when the elevator car is opposite the landing. When the door is opened the contactor is also opened, which prevents the operation of the elevator while the door is in the open position

The method of operating the car at first consisted of a mechanical device, either a rope, a wheel or a lever, connected through the proper gearing to the controller. Devices of this kind are still in use on freight and slow-speed passenger elevators. The modern elevator, particularly for high speeds, is provided with a master switch in the car, so arranged that it is returned to the central or off position if the operator releases the handle. In addition, a safety switch is usually provided to stop the car in case of accident to the master switch.

In private residences, hospitals and other places where the elevator is not used enough to warrant the expense of a regular operator, the push-button system of control is used (Fig. 407). This is an elaborated form of master switch. Each landing is provided with a push button to bring the car to that landing, and a set of push buttons is located in the car for dispatching it to a predetermined landing. These push buttons operate a selecting circuit which is opened by mechanical means when the car reaches that particular landing. A cam on the car unlocks

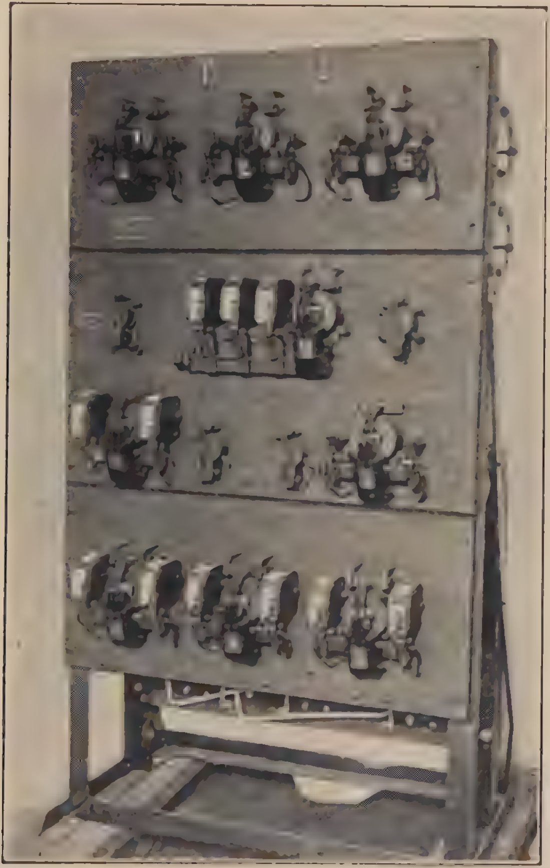

Fig. 409. Two-speed A. C. Elevator Control

the door when the landing is reached (Fig. 408), and the opening of the door breaks the control circuit so the car cannot be started until the door is closed again. A safety button is provided in the car for stopping the car at the will of the passenger. Many of these devices are in successful operation. They first began to meet with favor about the beginning of the present century. As far back as 1887, devices of this kind were applied to hydraulic elevators, the valves of which were controlled by electromagnets.

Alternating-current Elevators

About 1897, the alternating-current motor commenced to be a factor in the operation of elevators. These motors are of two types—squirrel-cage and wound secondary. The squirrel-cage motor is started and controlled merely by closing the primary switch, no external resistance being used. In small sizes, this motor presented no difficulties, but in sizes over five horsepower the early motors took so much current at starting that they caused serious disturbance to the power supply. At that time, very few central stations had sufficient line capacity for starting these large size motors. The wound-secondary motors were more common in the larger sizes. They have external resistance in the secondary circuit. This resistance was short-circuited during acceleration by means of a mechanical switch controlled by a dashpot. They were fairly successful for car speeds of 150 to 200 feet, but could not be used at higher speeds.

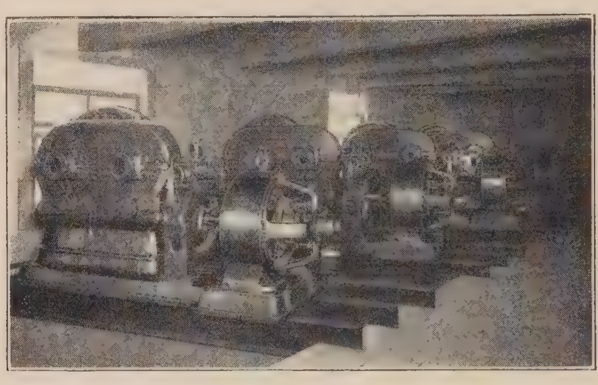

Fig. 410. Four Tandem Worm-gear Elevator Machines

Driven by direct-current motors. These machines are located above the hatchway, which is the preferable arrangement for an electrical machine. The tandem gearing is used for heavy loads. The two gear wheels mesh together and are actuated by right and left worms. This arrangement takes up all end thrust upon the worm shaft and is a very substantial construction

They also gave trouble due to the large amount of stored energy in their rotating elements. As the problem of induction motors for elevators became better understood by motor designers, a better type of induction motor was developed for elevator service. This motor had a long rotating element of small diameter, giving a minimum stored energy and having an electric design well adapted for heavy starting torque. The squirrel-cage motor of this type is designed to develop its maximum torque at starting, and takes a comparatively small current when it is first started. It is generally used in preference to the wound secondary type up to the 20-horsepower size, although a number of wound-secondary motors are used in small sizes where the power supply is limited. Larger motors of the same general design arranged with slip rings for external resistance at starting are also used.

The latest development in alternating-current elevator practice is a two-speed motor, the slow speed being usually one-third of the full speed. Such a motor is adapted for high-speed elevator work as the slow speed of the motor will enable the operator to control the car easily when making landings. It also permits a satisfactory top and bottom limit stop to be used. The car is made to approach either limit of travel on the slow speed, so that the mechanical brake can easily stop the car when the limit of travel is reached. The control for this motor (Fig. 409) consists of a reversing switch, a pole-changing switch, and an accelerating device for short-circuiting the secondary winding used in connection with the high-speed combination.

SUMMARY OF CHAPTER XXXIV

Electric versus Hydraulic Elevators: Electric elevators were at first used only in small installations, hydraulic elevators being used in large buildings. As the size of buildings increased, the inherent limitations of the hydraulic elevator became more and more marked, among which the following may be mentioned:

(1) The hydraulic elevator is a constant power machine—the same amount of water is required to move the car, whether empty of loaded.

(2) An expensive power plant and piping system are required.

(3) In order to circulate the water when descending, part of the car weight must be left unbalanced; that is, the car cannot be overbalanced.

(4) The maximum permissible height is limited.

Attention was therefore turned to the further development of the electric elevator, which had the following inherent advantages:

(1) The first cost is less.

(2) The maintenance cost is less.

(3) The operating cost is less, the power consumed being proportional to the load.

For tall buildings the electric elevator, in a recently improved form, is now the preferred type.

Forms of Drive: Various forms of drive were developed, a few of which may be mentioned:

(1) The motor was belted to a countershaft. The counter shaft included a driving sheave, operating the cable to which the car was connected. The car was reversed by shifting the belt. A mechanical brake was used. (This form of drive is no longer installed.)

(2) The motor was belted to a drum on which was wound the cable connected to the elevator. The direction was reversed by reversing the motor.

(3) The motor was geared through (a) a worm and wheel, or (b) a worm with right and left threads and two wheels, to the winding drum, the drum, gearing, and motor being mounted on a common bedplate. Method (b) avoided the worm shaft end thrust encountered in (a).

(4) (Traction elevator machine) The cable was moved by a driving sheave, with (a) one to one gearing (1:1 traction) or (b) two to one gearing (2:1 traction) between the car and the sheave. Later (c) the driving sheave was placed directly on the motor shaft, or, in (d) the gear type traction machine the motor shaft was geared through worm or herringbone gears to the driving sheave. The traction drive is inherently safer than the drum drive because the car or counterweight on reaching the bottom of its travel relieves the tension on the rope and allows it to slip on the driving sheave.

(5) (For low speeds and heavy loads, as in freight elevators) The motor drives the winding drum through a combination of worm and spur gearing. An internal gear is bolted to the end of the drum, meshing with a pinion on the end of the worm wheel shaft.

Smoothness of Running: Smoothness of running may be affected by various conditions, among them being the following:

(1) poor fit of guide shoes to guide rails;
(2) back lash in gears;
(3) roughness of worm wheel;
(4) loose end thrust bearings;
(5) failure of friction brake to operate smoothly and gradually;
(6) too rapid changes of rate of acceleration and retardation.

The last condition may be caused by large resistance steps. This is remedied by increasing the time constants of the motor, increasing the number of steps of resistance, and making acceleration automatic.

Overbalance: Cars are usually overbalanced, that is, balanced by a counterweight weighing more than the car, usually by one-half of the average load (= 30 to 40 per cent of the maximum load).

Limit Stops: The limit stops, or stops at the top and bottom of the elevator's travel, are usually made independent of the operator by means of stop motion gearing, a mechanical gearing on an extention of the shaft of the winding drum. Machine limit stops are driven by the machine; hatchway limit stops are placed in the hatchway and operated by the car in passing. Oil buffers placed at the limits of travel cushion the impact on stopping.

Function of Controllers: Elevator controllers should include:

(1) a line switch to disconnect the motor from the electric circuit;
(2) a reversing switch;
(3) an armature or field accelerating device;
(4) a dynamic brake;
(5) a mechanical brake;

(6) top and bottom limit stops;

(7) an operating handle or master switch in the car;

(8) (for drum machines) a slack cable switch;

(9) a motor overspeed switch to disconnect the motor when the car safety brake grips the guide rails;

(10) motor overload protection;

(11) an operator's emergency switch on the car;

(12) (for high-speed elevators) one or more slow-speed control points.

D-c. Installations: In d-c. installations a good starting torque was obtained by using a compound-wound motor. To procure good speed regulation after starting the series field was cut out. In an early form of controller the starting resistance was short-circuited by an arm, raised by a solenoid and retarded by a dashpot, which moved a brush over a series of contacts, first short-circuiting the starting resistance by steps, and finally the series field. The positive operation of the dashpot assisted materially in starting heavy loads. The arm was moved by a shunt coil energized by the counter e.m.f. of the motor. Later the dashpot was omitted and individual contactors were used, operated by the counter e.m.f. of the motor. The line switch was replaced by an electrically-operated contactor.

When the two to one adjustable-speed shunt motor was first used, the car jerked on changing speeds. This was remedied by a fluttering relay, which strengthened the field when the current was excessive and weakened it by inserting resistance when the current dropped to a proper value. As the speed of cars increased it was necessary to add slow-speed points. One method was to add resistance in shunt with the armature, besides the resistance in series with it. At the same time the shunt field was strengthened.

Operating Handle: The operating device at first consisted of a rope, or wheel, or lever, connected through gearing to the controller. This has been replaced in high-speed elevators by a master switch placed inside the car. This switch returns to the off position when released. Jerking of the car in modern elevators is usually due to improper manipulation of the operating handle.

Push Button System: In the push button system of control, the button closes a selector circuit which is opened by a mechanical device when the car reaches the landing selected. The door is then unlocked, and when opened, a door switch breaks the control circuit so that the car cannot be started until the door is closed.

A-c. Installations: In a-c. installations the squirrel-cage motor was at first used, but in sizes over five horsepower the heavy starting current caused line disturbances which led to the substitution of wound secondary motors for larger installations. However, to reduce its stored energy the diameter of the squirrel-cage rotor was decreased, and to enhance its starting torque the secondary resistance was increased, so that in most cases, up to 20 horsepower in size, this type is preferred. A two-speed a-c. motor, with a speed range of three to one, has been successfully developed for elevator service.

CHAPTER XXXV

ELEVATORS, VARIABLE VOLTAGE CONTROL

The high-speed elevator—why passengers experience discomfort—the ideal curve of acceleration and retardation—how obtained in the variable voltage system—functions of the control scheme—advantages of the variable voltage system.

In the development of the electric elevator to replace the hydraulic elevator for large buildings many problems were encountered. Elevators built for low speeds were safe and reliable in operation, but when the speed was increased, to take care of office building service, and higher rates of acceleration were introduced, many changes in the method of control were necessary to obtain smooth operation.

Elevator cars for such service should be accelerated and retarded at as high a rate as possible without causing discomfort to the passengers. The uncomfortable feeling experienced by passengers in high-speed elevators is not due to the high rate of acceleration but to a too rapid change of rate of acceleration. Any sudden change in the rate of acceleration, such as occurs when a step of resistance in the motor circuit is short-circuited, causes a jerk or bump which is disagreeable. In slowing down the car to make a landing the same condition holds; the rate of change of acceleration should be kept uniform.

The sinking feeling experienced by passengers when a fully loaded car is accelerated in the down direction with the ordinary rheostatic controller is largely due to the fact that the rate of change of acceleration is too rapid. When the motor is connected to the line to start the elevator, practically the only retarding force is friction in the machinery. The motor is taking power from the line and assisting in accelerating the car. No retarding torque is obtained from the motor until its counter e.m.f. exceeds the line voltage and it is transformed to a generator. Retardation is then quite abrupt, as a small change in speed makes a considerable difference in the amount of current returned to the line by the generator action of the motor. A resistor may be connected in parallel with the armature of the motor during a portion of the accelerating period, in order to retard this acceleration, but the results thus obtained are usually not very satisfactory.

With the variable voltage control system described in Chapter XX, the motor armature is connected by a low resistance circuit to the generator armature. When the car starts downward with a heavy load the elevator motor becomes a generator, delivering power as soon as a low voltage value is reached to the motor-generator machine. The speed of the elevator cannot increase any faster than the increase in voltage of the motor-generator machine. A positive method is thus provided for controlling the acceleration under heavy load conditions.

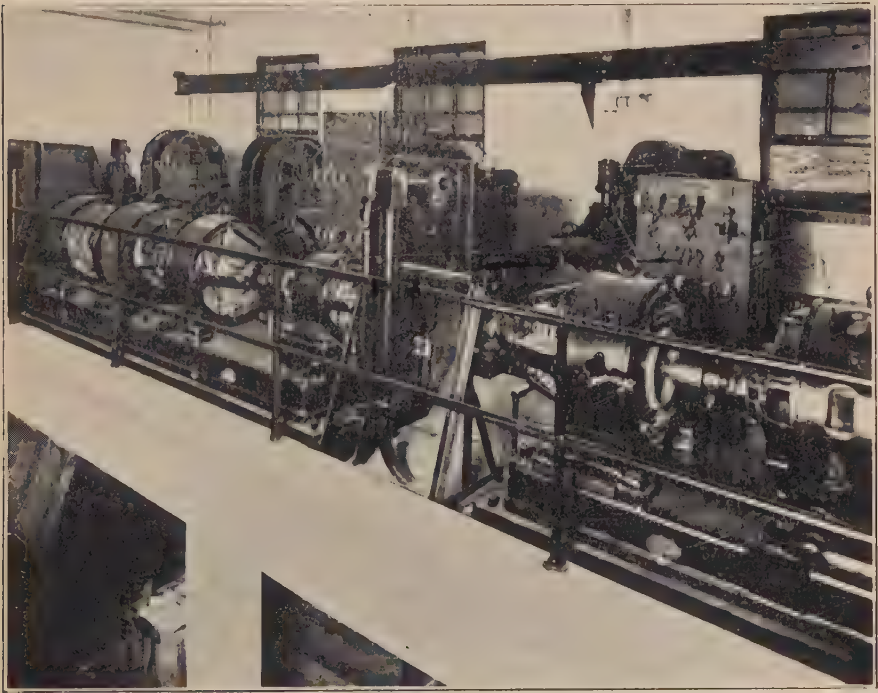

FIG. 411. Installation of Geared Traction Elevators and Variable Voltage Control, Showing the M. G. Sets in the Foreground

When the car is accelerated in the up direction under load the elevator motor can obtain power for acceleration only at the rate at which the generator builds up its field. It is evident, therefore, that the rate of acceleration under all conditions of load is approximately the same, and depends upon the speed at which the generator field builds up.

In stopping the car the same condition exists. The elevator motor decreases in speed at the same rate that the generator field decreases, which means that the rates of acceleration and retardation can be positively controlled by adjusting properly the field constants of the generator machine.

The shape of the ideal acceleration curve, when speed is plotted against time, is similar to the letter S (Fig. 412). Starting at the zero point, the car accelerates slowly, the rate increasing until half speed is reached, after which the rate of acceleration gradually decreases to zero when the car is running at full speed. In stopping, the curve of retardation should be the reverse.

If the generator fields are connected to full voltage, they build up very quickly at first, the increase in field strength afterward tapering off in accordance with a logarithmic curve. The latter portion of this curve is of a right shape to correspond with the ideal curve of acceleration, but the first part of the curve is of a wrong shape. If, however, we place a heavy damper winding on the field poles of the generator, we find that the increase in field strength is very gradual at first, although the total time required to reach full field strength is not materially changed. This proves to be the key to the situation. By proportioning properly the damper winding, the building up of the field of the generator may be made to approximate closely the ideal curve of acceleration.

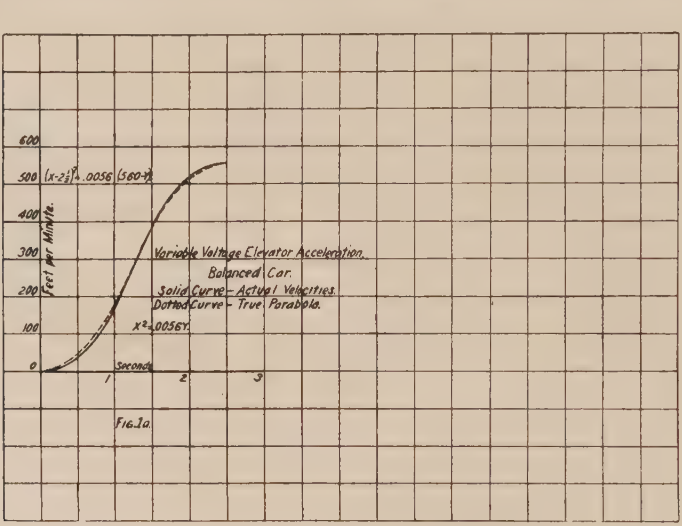

Fig. 412. Ideal Acceleration Curve Speed-time

The result of these improvements has been a control system that accelerates and retards the elevator car in a positive manner, and without discomfort to passengers. The time of acceleration and retardation can be adjusted by changing the proportions of the generator field, also by introducing resistance both in series and in shunt with this field, as explained in Chapter XXXIV.

In stopping the car it is necessary to neutralize the residual magnetism in the generator field. This is accomplished by means of a low resistance auxiliary winding on the field magnet. At the time of stopping this is connected across the terminals of the generator in the proper direction to demagnetize the field. As long as there is sufficient residual magnetism to generate voltage, current will flow in this winding, setting up a magnetomotive force opposite in direction to the residual magnetism; this force of course becomes zero as soon as the magnetism is neutralized. In other words, the generator is made to kill its own field.

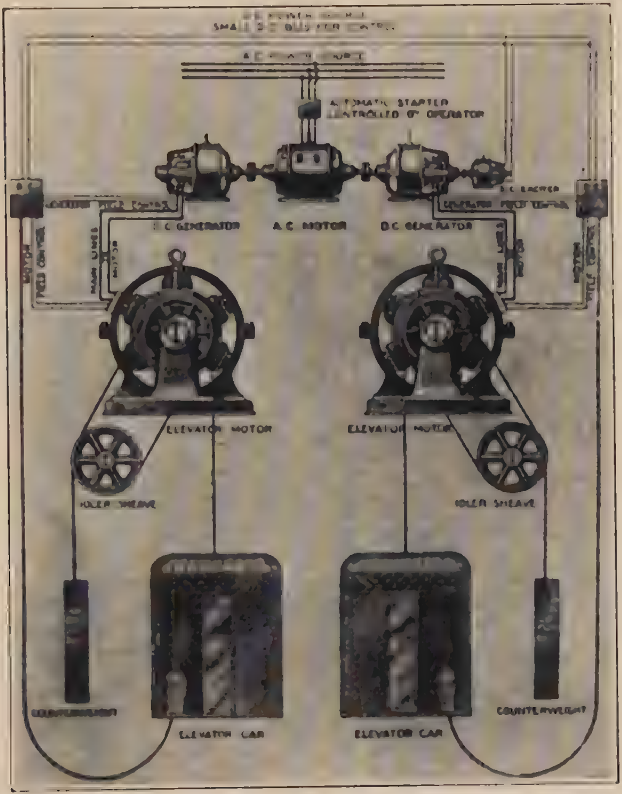

FIG. 413. General Scheme of Control for Variable Voltage System

The brake magnet is adjusted to release, allowing the brake to set, at the time the car is brought to rest. Ordinarily the function of this brake is only to hold the car firmly at the landing, the stopping being done by the regenerative action of the motor. When the car switch is thrown abruptly to the off position the brake circuit is not immediately released, but is maintained by relays until the generator voltage has reached a low value. The time of the setting of the brake is further retarded by proper adjustment of the discharge resistance connected in parallel with the brake coil.

An emergency switch is provided in the elevator car. In case of accident the operator opens this switch; this immediately sets the magnetic brake, and at the same time disconnects the motor from the generator and short-circuits the motor terminals through a dynamic brake resistor. This will give a rather abrupt stop, but not sufficiently rough to injure the passengers.

The general scheme of control is shown in Fig. 413. The generator is driven by an a-c. motor, and the set has a direct connected exciter. The speed of the car is controlled by a combined master switch and field rheostat. This makes rather a large car switch, but permits a considerable number of operating speeds. Ordinarily, three operating speeds in either direction of travel are all that are necessary, which permits contactors located on the control board to be used for changing the field strength of the generator and results in a much smaller car switch. The complete diagram shows several additional contactors which take care of the brake circuit and perform other detail functions. Fig. 414 illustrates a controller panel of this type. The elevator machine may be any of the usual types, as illustrated in the previous chapter.

The elevator controller performs the following operations:

(1) connects the generator field to the excitation voltage in the proper direction for up or down motion of the car;
(2) energizes the brake coil (the brake coil is opened on both sides and is fed through the same contactors that energize the generator field);
(3) controls the car speed by controlling the excitation of the generator field;
(4) provides the proper discharge circuits for the generator field during retardation;
(5) connects in circuit an extra demagnetizing field on the generator in stopping;
(6) opens the connection between the generator and elevator motor after the car has come to rest;
(7) controls the setting of the brake by means of its own self induction and so obtains a smooth stop.

A complete discussion of this system of control was given for the A.I.E.E. proceedings and can be found in their transactions.[1]

An interesting addition to this system of control is an automatic means for making a car landing. By compounding properly the machines the elevator motor can be made to operate at practically a constant speed regardless of the load. This means that the elevator can be operated at a very low speed, from which the landing can be made. Such close speed regulation at low car speeds has not been obtained with any other form of controller. The same results have been accomplished by using an auxiliary gearing but with added complications to the elevator machine.

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[1] Variable voltage control system, as applied to electric elevators; by E. M. Bouton, Transactions A.I.E.E., February 4-8, 1924.

Switches can be provided, either placed in the hatchway or driven by the elevator machine, to reduce the car speed, automatically, to a very low value when approaching a landing. A switch located on top of the car engages a cam in the shaft when the car is close to the landing; the cam actuates the switch to stop the car flush with the landing. With automatic landing control the least amount of time is consumed in bringing the car flush with the landing. Retardation can be commenced at the last possible part of the travel and the car stopped without overrunning. When a landing is made by the operator, the slowing down of the car usually takes place a little earlier than necessary, in order to make sure that the car is under slow speed control when the landing is reached. The accurate speed regulation obtained with the variable voltage control system can be used in conjunction with an indicator inside the hatchway. If the operator throws the car switch to the off position

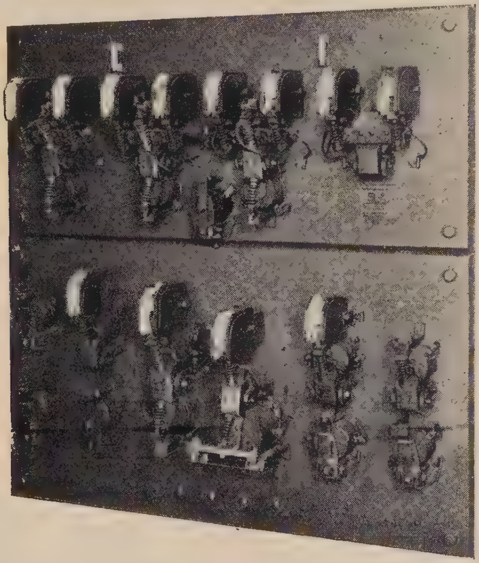


FIG. 414. Variable Voltage Control Panel

when opposite this indicator the car will stop close to the landing without a further manipulation of the car switch.

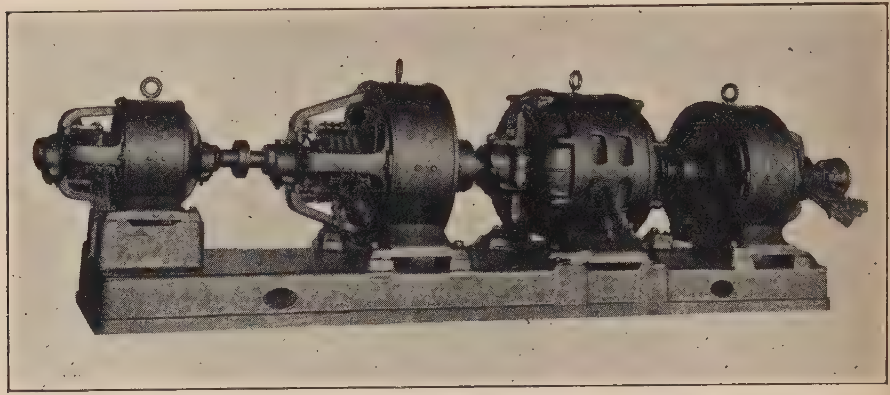


FIG. 415. Motor-generator Set for Two Elevators Using Variable Voltage Control
An a-c. motor drives two d-c. generators and one exciter

The development of the variable voltage system of control has resulted in the following advantages:

(1) Elevators running at the highest speeds may be driven from a-c. supply lines of any commercial voltage and frequency.
(2) The acceleration and retardation are perfectly smooth and uniform.
(3) A high rate of acceleration and retardation is obtained, which permits the use of high car speeds and increased elevator capacities.
(4) Positive speed control under all conditions of load makes it easy for operators to land the car accurately without loss of time.
(5) A number of inherent safety features make it particularly suitable for high car speeds.
(6) Maintenance costs are reduced to a minimum and the reliability of service is increased because of the simplicity and flexibility of the system and because no large currents are ruptured in operation.
(7) The variable voltage system requires less power for acceleration and retardation because of the absence of rheostatic losses and because of the power returned to the line during retardation and in making the limit stops.
(8) Very little power is taken from the line to make small movements of the car, due to the low generator voltage.
(9) Low speed running does not increase the power consumption.
(10) The greatest gain in economy will be shown where the number of starts and stops is large.
(11) The waste of power during long rest periods can be eliminated by shutting down the motor-generator set with a start and stop push-button station, which may be located at a point accessible to the starter or mounted in the car.

SUMMARY OF CHAPTER XXXV

Discomfort to passengers in high-speed elevators is due to too rapid changes in the rate of acceleration. A loaded car when started downward is accelerated both by the motor and by gravity and retarded only by the friction in the machinery. When the motor reaches a speed sufficient to generate a voltage greater than the line voltage a sudden retardation results. With the variable voltage system, however, the line voltage (in this case the voltage of the individual generator) is kept low and the retardation of the motor begins as soon as the motor is generating a low voltage; the speed is thus under control at all times. Both in stopping and in starting the speed is dependent upon the rate at which the generator field builds up.

An ideal acceleration and retardation curve resembles the letter S. If the generator field is connected to full voltage at starting the latter part of the building up period conforms to this ideal curve, but during the first part of the period it builds up too rapidly; this is remedied by a damper winding on the field poles, slowing it down. The acceleration and retardation can thus be controlled—

(1) by proportioning the generator field;
(2) by proportioning the damper winding;
(3) by inserting resistance (a) in series and (b) in shunt with the generator field.

The car is stopped by the regenerative action of the motor. The magnetic brake is held open until the car stops, when the magnet releases, allowing the brake to set. When the car is stopped a low resistance auxiliary winding is connected across the generator terminals, the flux generated, due to the residual magnetism in the generator field, being used to kill the residual magnetism. An emergency switch in the car, when operated, sets the brake instantly, disconnects the motor from the line, and connects it to the dynamic braking resistor, giving an abrupt stop.

The generator field rheostat is combined with the car master switch. This makes rather a large car switch but gives a number of operating speeds. In many cases three speeds only are sufficient, when the field strength can be changed by contactors on the control panel, and a smaller car switch used.

The controller—

(1) energizes the generator field for up or down motion;
(2) releases the brake;
(3) controls the speed by controlling the generator field;
(4) discharges the generator field during retardation;
(5) connects a demagnetizing field on the generator when stopping;
(6) opens the circuit between the motor and generator after the car stops;
(7) effects smooth stopping by controlling the brake by self induction.

By properly compounding the machines good speed regulation is obtained, even at slow speeds, hence a low speed can be used to assist in landing.

Automatic landing: at a certain point in the hatchway an indicator is passed, when, if the operator moves the operating handle to the off position, switches in the hatchway will slow the car down and when close to the landing a cam in the shaft engages a switch on top of the car, stopping the car flush with the landing.

Advantages of the variable voltage system of control:

(1) high-speed elevators may be driven from alternating current of any commercial voltage and frequency;

(2) the motor is accelerated and retarded smoothly;

(3) a high rate of acceleration and retardation may be obtained without causing discomfort to passengers;

(4) inherent safety features permit high speeds;

(5) positive speed control is had at all loads;

(6) maintenance costs are reduced;

(7) less power is required in acceleration and retardation, because of reduced resistance losses and regenerative action;

(8) in making small movements of the car little power is consumed;

(9) running at low speed does not increase the power consumption;

(10) a still greater saving appears when the number of starts and stops is large;

(11) during idle periods the motor-generator set may be shut down and all standby losses eliminated.

CHAPTER XXXVI

OIL WELLS

Oil fields—electric drive dependent upon proximity of central station—pumping wells—pulling tubing—deep well requirements—drilling service—cable drilling—rotary drilling—advantages of electric drive.

OIL is used extensively in industrial establishments today and has entered into many phases of everyday life. Next to coal, it is our principal source of power. Many of our battleships and merchant vessels, as well as railway locomotives, use oil for fuel instead of coal. During 1923 the production of crude oil in the United States was about 730,000,000 barrels, or two thirds of the world's total production.

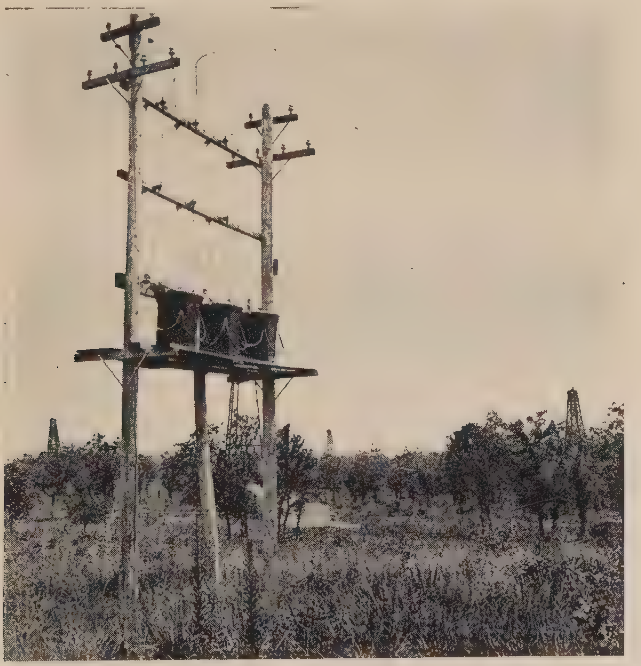


FIG. 416. A Transformer Sub-station in an Oil Field
With derricks in the background

The distribution of oil wells in the United States may be divided broadly into five fields, as follows:

(1) Eastern or Appalachian field: These oils are generally of the paraffin base and are large producers of gasoline and lubricating oil. The wells are gaseous and gas engines are extensively used for pumping.

(2) Midcontinental field, including Kansas, Oklahoma, and Northern Texas: This field produces oils having both paraffin and asphaltum bases. In this field there are several thousand wells operated by electric motors and new wells are being equipped with electric drive.

(3) Louisiana and Southern Texas: These wells are principally of the asphaltum base. The electric drive is being introduced and a number of wells are already equipped.

(4) Colorado and Wyoming field: This field produces oil with a paraffin base. It is a new field and the development was retarded by lack of material during the war. Recently electrical equipment has been applied extensively.

(5) California field: The oil in this field has an asphaltum base and the pumping has been done by burning oil under boilers to produce steam. This practice was very uneconomical and the electric drive has found its widest application here, there now being several thousand wells equipped with electric motors obtaining power from hydro-electric plants. This number will be materially increased when additional electric power is available.

The introduction of electrical equipment for oil wells has been gradual, and there was much skepticism expressed at first as to the feasibility of this drive. It is dependent upon central station power for its economic operation and it is not probable that any considerable development will take place in fields which are not adjacent to large central station lines. In southern California, due to the far-sighted policy of two of the large power companies, this development has been carried forward rapidly. The power company supplies the high tension service to a centrally located substation where outdoor-type transformers step down the power to the low-voltage distributing system. The electric meters are located at this substation and the distribution is taken care of by the owners of the lease. In addition to pumping and pulling the wells, electric power is available for operating the machine shops, pumping stations, dehydrating plants, and for welding the pipe joints for pipe lines. It also furnishes light where required and can be made of general service throughout the whole lease. The use of welded joints on pipe lines is a comparatively recent development and is rapidly superseding the screw joints, where electric power is available for welding purposes. Welded joints remain tight and materially reduce the loss from leakage. The pipe sections can readily be cut apart with the electric arc, where renewals or changes are required.

When an electric motor is applied to a well, it must perform two functions; namely, pumping and pulling. The pumping service is used about 98 per cent of the time. With the pulling service is included the lifting and lowering of tubing and tools, the cleaning of the well, which is known as "swabbing," "agitating," baling sand and other general work.

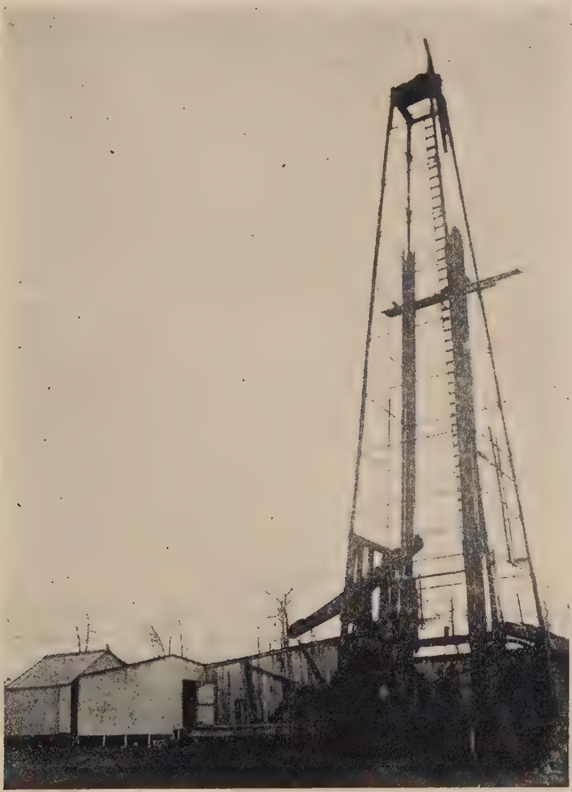


FIG. 417. An Oil Well Equipment

Showing stands of tubing resting against the side of a derrick

PUMPING

This application does not differ from an ordinary pumping installation, as far as the electrical equipment is concerned. For the shallower wells, a squirrel-cage induction motor is commonly used, operating on what is known in the trade as "steel pumping power." This rig may also be used to pump water from gas wells. The motor is started by connecting it directly to the line, as only a small motor is required.

For pumping service the primary windings of the motor are connected in star and are protected by fuses. When it is necessary to pull the tubing the motor primary is connected in delta by means of a switch which may be conveniently mounted on the motor frame. One position of this switch connects the primary in star and the other in delta. The motor is started, stopped, or reversed by a small drum switch which connects the motor windings directly to the line. The overload protection usually consists of fuses. Where overload protection is provided for the pumping only, the fuses are cut out of the circuit during the pulling operation. If fuse protection is required during pulling, a larger set of fuses must be connected to the circuit.

Where the oil wells are shallow, a form of pumping power is sometimes used, known as "band wheel power," which is connected to a number of wells, usually from fifteen to twenty. These wells are grouped together and pumped by means of pull rods running from the well to the "power." By balancing one well against another, the pull can be distributed throughout the revolution of the band wheel and a remarkably small amount of torque is needed for operating the pumps. The band wheel is driven by a wound-secondary induction motor, so that the speed may be adjusted. When properly installed and connected up the operation is very smooth and makes an ideal application for an electric motor.

Deep wells are pumped by individual motors of the wound secondary type. These motors are started by inserting resistance in the secondary circuit. The primary is provided with low voltage protection and is connected to the line through a time element overload relay.

Pulling Service

Under pulling service are included numerous miscellaneous operations. The principal function, however, is to pull the tubing out of the well and replace it. It is necessary to pull the tubing in order to clean out the well, when it becomes clogged with sand, or a new working barrel installed. During this time the well is not producing oil and there is a direct loss of production. Furthermore, since oil is of a migratory nature, the operators feel that they are actually losing the oil which they do not pump. It is therefore desirable to reduce this inactive period as much as possible.

The time required for pulling the tubing and cleaning is proportional to the depth of the well. For shallow wells, which are pumped by squirrel-cage motors, the pulling is effected by erecting an A-shaped derrick above the well and pulling the pipe out in short sections. The pumping motor can be used and the extra torque for pulling purposes obtained by connecting the primary windings in delta. The motor is coupled to a hoisting drum by means of a clutch. Pulling service requires a reversal of the motor, which is obtained by the used of a small drum reverse switch. The motor is connected to the line by moving the drum switch to either the forward or reverse directions.

Deep wells, having a standard rig, use wound secondary induction motors. Where a two-speed motor is used, the slow speed is for pumping and the high speed for pulling. The pump may operate for short intervals of time from the high speed connections for "shaking the well" or agitating the sand at the bottom of the well. Often this agitation will make it unnecessary to pull the tubing. It takes only a few minutes and may effect a considerable reduction in the idle period of the well.

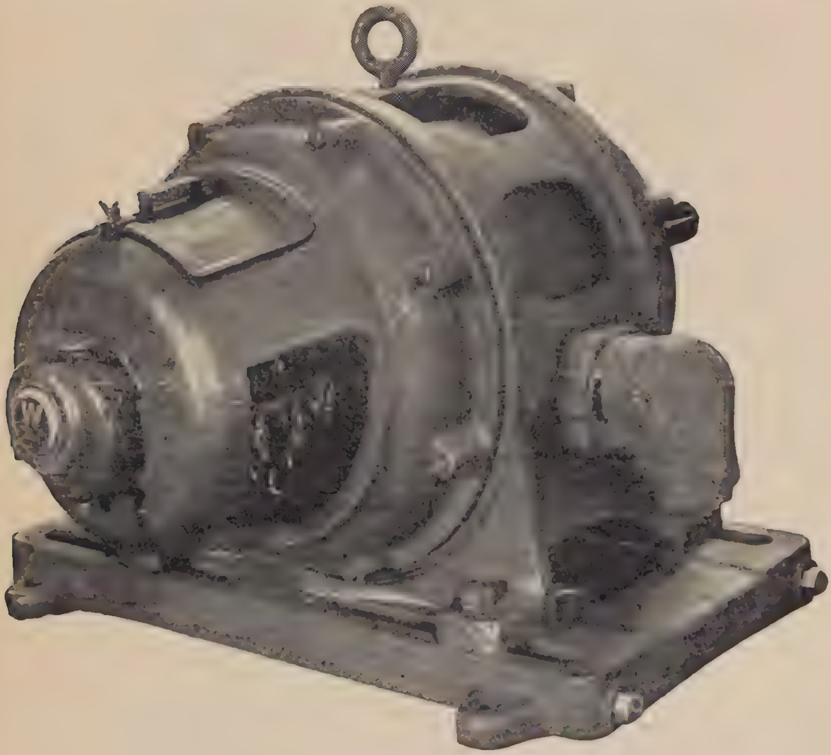


FIG. 418. Type of Two-speed, Variable-speed Oil Well Drilling Motor with Bedplate

DEEP WELL EQUIPMENT

The service requirements for deeper wells are severe and a number of years of experience were required before electrical engineers were able to develop a satisfactory motor and controller for the application.

Many of these wells are now served by a two-speed wound-secondary induction motor, both the primary and secondary having different connections for the high and low speeds. This motor is rated at 30 horsepower at the high speed and 15 horsepower at the low speed: these, however, are only nominal ratings, and their load during pulling is very heavy and approaches the pull out torque of the motor. This means that the electrical connections in both the motor and controller must be heavy so that they will not be injured during the short time that the abnormal load conditions exist.

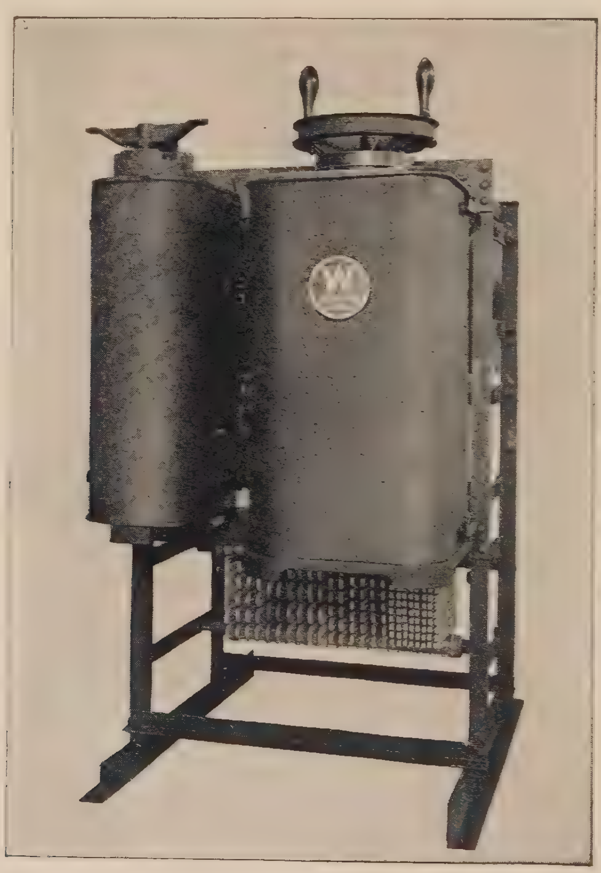


FIG. 419. Front View of Oil Well Control Unit

The motor is illustrated in Fig. 418. It has six primary and six secondary leads. The slip rings are provided with a cover to protect them from dripping. The whole mechanical structure is heavy and rugged, in order to withstand the severe conditions of handling and operation.

The controller is a self contained unit, and is illustrated in Figs. 419, 420, and 421. It consists of the following:

(1) An entrance switch, for disconnecting purposes.

(2) An oil-immersed circuit breaker, provided with overload and low voltage protection. The overload coils have two connections, a heavy wire connection with few turns, for use with the 30 horsepower circuit. In series with this coil are a larger number of turns of smaller wire, for use in circuit with the 15 horsepower connections. The circuit breaker is of weatherproof construction.

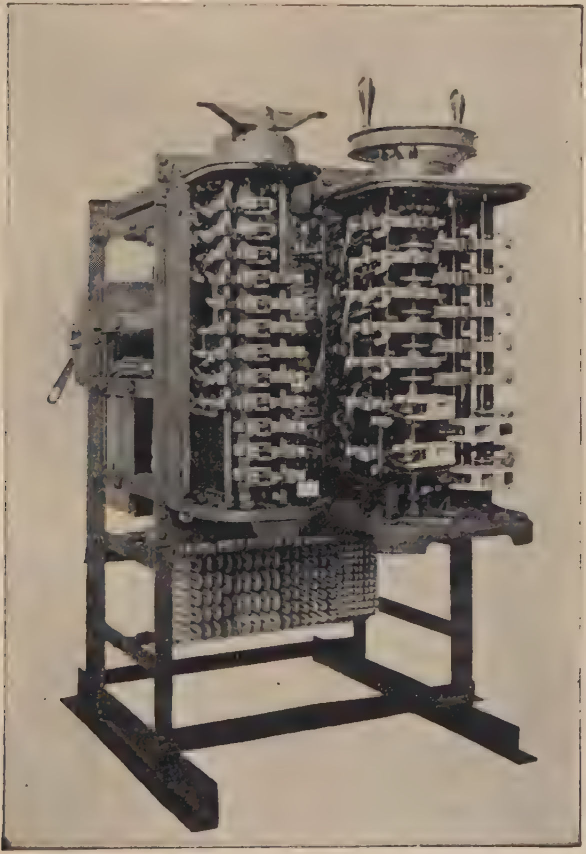


FIG. 420. Control Unit with Covers Removed

(3) A pole changing switch having an off position and two operating positions, one giving low speed and the other high speed.

(4) A speed controller of the cam type, for starting and stopping and

reversing the motor. The controller here illustrated gives nine points of speed control in each direction of operation. The cam contactors in the primary circuit are provided with individual magnetic blowouts.

(5) A cast grid resistor connected to the secondary of the motor and used for speed regulation. In order that the same resistor may be used for both the high-speed and low-speed combinations, it is necessary so to proportion the secondary windings of the motor as to give the proper ratio of volts to amperes. On the high-speed connection a small section of resistance is connected permanently in the secondary in order to give the proper shape to the speed torque curve.

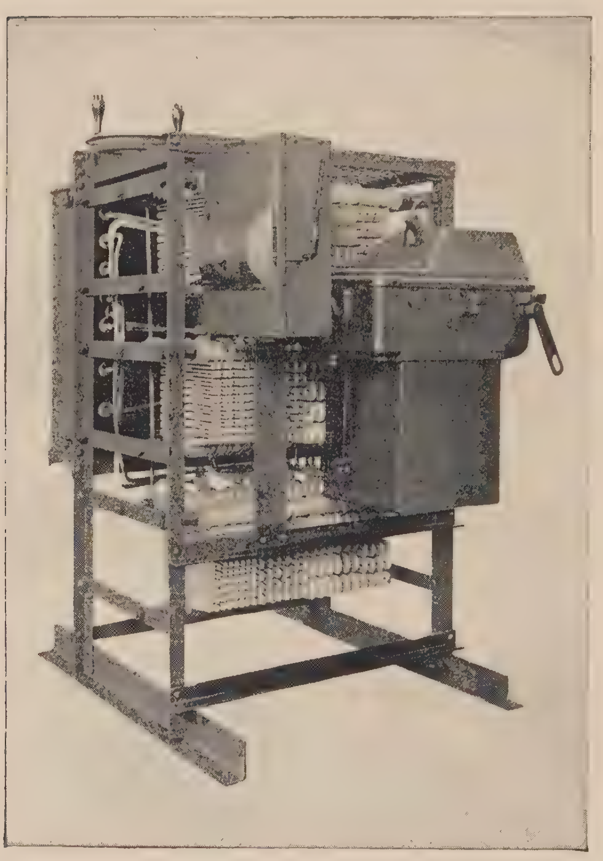
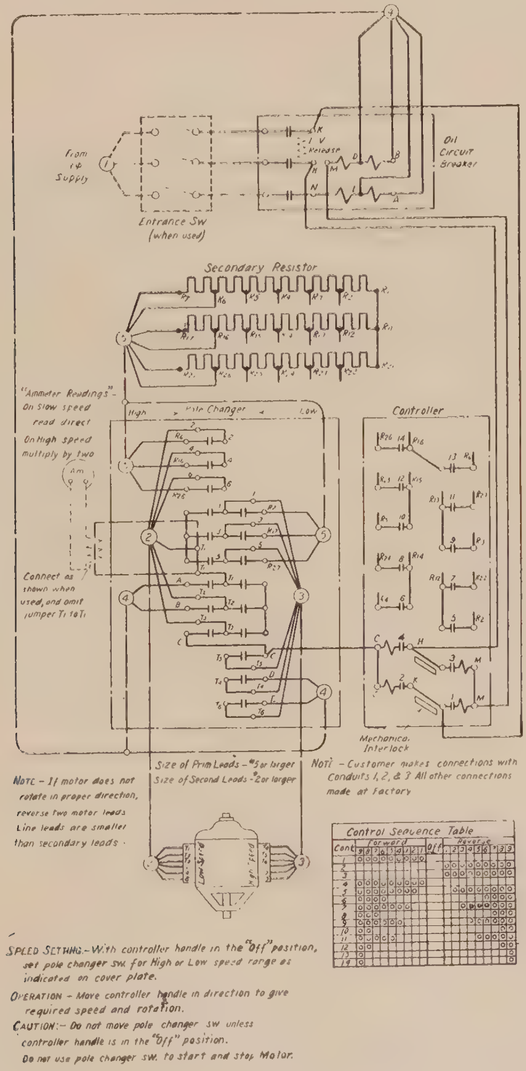


FIG. 421. Rear View of Oil Well Control Unit Showing Circuit-breaker and Safety Entrance Switch

(6) An angle iron framework for supporting the equipment. The resistor is mounted inside of the framework and so arranged that each section of grids can be removed independently, without disturbing the rest of the equipment. On the rear of the framework is mounted the

entrance switch and circuit breaker; on the front, the pole changer and controller.

The scheme of control is shown in Fig. 422. Since all of the functions of the controller are performed by manual operation, the connections are simple and easy to follow. The only adjustment is the overload trip of the circuit breaker; all of the wiring is completed at the factory,



Size of Prim Leads - #5 or larger
Size of Second Leads - #2 or larger

NOTE - If motor does not rotate in proper direction, reverse two motor leads Line leads are smaller than secondary leads.

NOTE - Customer makes connections with Conduits 1, 2, & 3 All other connections made at Factory

Control Sequence Table

Cont	Forward									Off	Reverse								
	9	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9
1	○	○	○	○	○	○	○	○	○										
2											○	○	○	○	○	○	○	○	○
3											○	○	○	○	○	○	○	○	○
4	○	○	○	○	○	○	○	○	○										
5	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○
6	○	○	○	○												○	○	○	○
7	○	○	○	○	○	○	○						○	○	○	○	○	○	○
8	○	○	○														○	○	○
9	○	○	○	○	○	○								○	○	○	○	○	○
10	○	○																○	○
11	○	○	○	○	○										○	○	○	○	○
12	○	○																○	○
13	○																		○
14	○																		○

SPEED SETTING.-With controller handle in the "Off" position, set pole changer sw. for High or Low speed range as indicated on cover plate.

OPERATION - Move controller handle in direction to give required speed and rotation.

CAUTION:- Do not move pole changer sw unless controller handle is in the "Off" position.
Do not use pole changer sw. to start and stop Motor.

FIG. 422. Diagram of Two-speed Oil Well Equipment

so that only the external connections are necessary to be made in the field. These consist of three line wires and twelve motor wires.

A push button can be mounted on the derrick to provide for emergency stopping in case of accident, or several buttons can be used if desired. This button operates the low voltage trip in the circuit breaker.

Drilling Service

Where electric power is available new wells are drilled with electrical equipment. There are two methods of drilling, known as cable drilling and rotary drilling.

Cable Drilling

This method is the older and perhaps the better known of the two methods. The drilling rig is substantially the same as that used with a steam engine, a motor being substituted for the engine. Drilling is effected by attaching the string of tools to the end of a rope or cable.

The horsepower required for drilling is greater than that for pumping, so that either a larger motor must be used, or two of the standard pumping motors in combination. A very convenient arrangement for drilling is shown in Fig. 423. Two standard pumping motors are belted to the drilling rig, each connected to its standard controller. For operating the cable with the string of tools both motors are connected for the same speed combination. The best adjustment of speed is obtained by operating one controller a notch or two in advance of the other. The changing of one controller causes it to operate in a differential ratio with the other controller; with a little practice the operator can obtain any speed combination desired. The horsepower required for the drilling operation depends on the depth of the well and the speed of drilling. The maximum horsepower of both motors is required for pulling the casing and hoisting the tools. In order to save time the tools are hoisted at maximum speed.

In deep wells, the driller starts in with a large size casing and decreases the size as the depth of the hole increases. Sometimes the hole is not entirely straight, due to a boulder or other hard substance being located at one side of the hole. This deflects the drilling tool slightly. In putting the casing in past a crooked spot of this kind, it is necessary first to drop the casing and raise it again, repeating this operation a number of times until the casing passes down free of the obstruction. To do this with large casings requires motors which will develop from 100 to 150 horsepower for short intervals.

ROTARY DRILLING

This method of drilling has been recently developed. The drill consists of a hollow spindle provided with a cutting tool at the lower end. Mud is pumped down through the center of the spindle and comes up between the spindle and the casing. This lifts to the surface the material cut by the drill. This process is continuous throughout the length of one section of the drilling spindle. When rock or other hard substances are encountered the load on the drill increases and the speed of operation is reduced. The casing surrounding the drill usually follows the drill down, due to its own weight; when it encounters an obstruction, it must be driven down. When drilling through certain kinds of earth the mud operates as a seal to keep out the water and the casing is not necessary. In deep holes the mud is forced down the drill spindle at a pressure of 1200 pounds per square inch.

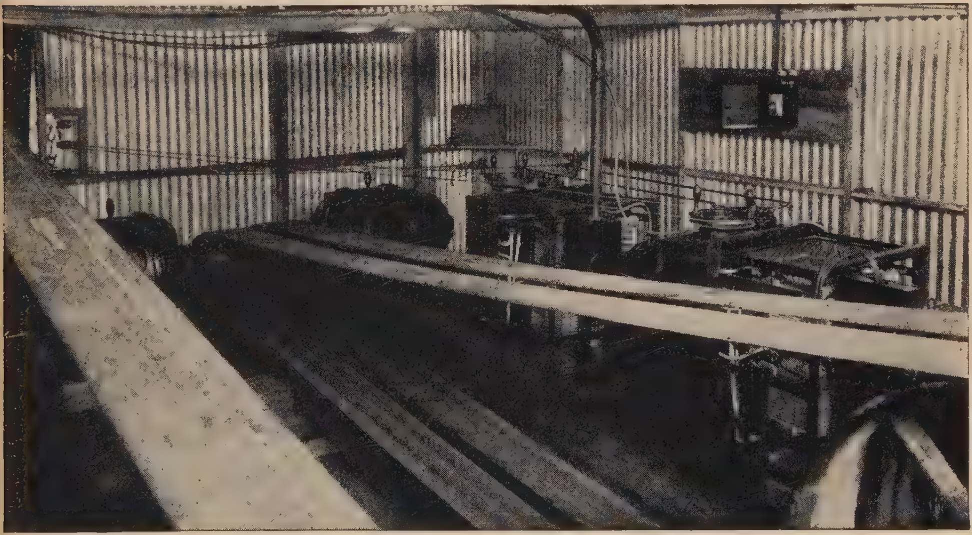


FIG. 423. Twin Motor Drilling Equipment Showing Control

The drill spindle is made in sections so that it can be withdrawn readily and the cutting tool removed. It is sometimes necessary to change this tool several times a day.

The controller used for this drill must give a wide range of speed, but the adjustment need not be as accurate as for cable drilling.

The advantages of electric power for pumping and drilling may be summarized briefly as follows:

(1) ease of installation;
(2) continuity of service;
(3) relatively low costs of power;
(4) absence of standby losses;
(5) close and accurate speed adjustment;
(6) greater speed for cleaning and pulling;

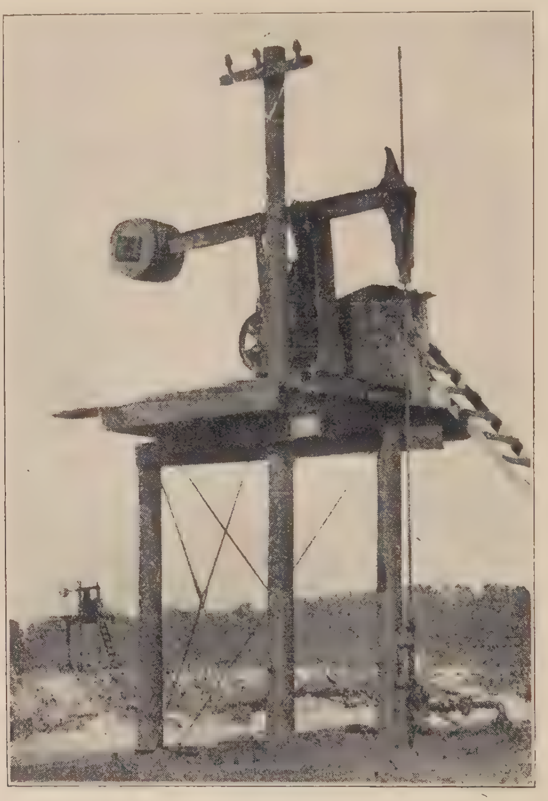


FIG. 424. Steel Pumping Power

The electric motor is located in the wooden enclosure at the right. The wells shown are in the bed of the Arkansas River in Oklahoma, the platform being raised above high water level. Pumping is continued during high water, the control being located on the river bank

(7) complete control from the headache post for starting, stopping, reversing, and close speed adjustment;
(8) safety to persons—the electrical equipment provides inherent safety features that cannot be obtained with a steam or gas driven equipment;
(9) low maintenance cost. Where a duplicate equipment is used for drilling the extra equipment can be moved to another well and a single equipment left for pumping and pulling service.

The motors for both pumping and drilling should have a high efficiency and power-factor, as these operations are continuous and the performance of the motor materially affects the power consumption. The introduction of electric motors and controllers has increased the production and earnings of oil wells on account of the ease with which the exact speed can be adjusted. The aim of the operator is to get maximum production at all times. There must be a minimum of delays due to breakdowns or repairs. Every shut-down means less production and a loss to the producer. The electric equipment has demonstrated its ability to furnish this service with a minimum of repairs and attention. In many cases the cost of the electrical power is more than made up by reduction in the repairs which were formerly necessary with the older methods of drive. In addition, the increase in production has been a material factor in the success of the electrical equipment. Electric drive is now being adopted in the oil fields as rapidly as central station power is made available.

SUMMARY OF CHAPTER XXXVI

Oil Fields: Oil wells in the United States are located approximately in five fields, as follows:

(1) Eastern or Appalachian field (paraffine base);
(2) Midcontinental field, including Kansas, Oklahoma, and Northern Texas (paraffin and asphaltum base);
(3) Louisiana and Southern Texas (asphaltum base);
(4) Colorado and Wyoming field (paraffin base);
(5) California field (asphaltum base).

Electric Power Supply: The feasibility of electric drive for oil wells depends largely upon the proximity of central station power. In Southern California power companies supply high tension current to centrally located substations, stepped down by outdoor transformers to a low voltage distributing system, the latter being administered by the owners of the leases.

Pumping: Ninety-eight per cent of the time the motor is engaged in pumping service, the rest in pulling (including lifting and lowering tubing and tools, cleaning or swabbing the well, agitating, baling sand, etc.). For shallow wells a squirrel-cage induction motor installation is used (steel pumping power). During pumping the primary windings are connected in star and protected by fuses; for pulling service the fuses are emitted and the windings are connected in delta. In band wheel pumping power, 15 or 20 wells are grouped and pumped by means of pull rods connected to a band wheel, the wells being balanced against each other so as to distribute the pull uniformly throughout the revolution of the band wheel.

Pulling: Pulling consists principally of pulling tubing from the well, as when the well is clogged with sand, or when a new working barrel is installed. Pumping at high speed to shake the well or agitate the sand at the bottom sometimes clears obstructions and makes it unnecessary to pull the tubing.

Deep Well Equipment: Deep wells require more rugged equipment. The motor has six primary and six secondary leads, for changing the number of poles, and is rated 30 horsepower at the high speed and 15 horsepower at the low speed. The controller is a self-contained unit, consisting of an entrance switch, an oil-immersed circuit breaker with overload and low voltage protection, a pole changer, a cam controller for starting, stopping, reversing, and speed control, and a cast-iron grid resistor for speed regulation, the whole mounted on an angle iron framework. The controller is completely wired when manufactured, except for the external connections (three line leads and 12 motor leads.) Stop push buttons may be added, mounted at the well where convenient.

Cable Drilling: In cable drilling a string of tools is lifted by a cable or rope and dropped on the rock's surface. Twin motors are used, the controller of one being advanced a notch or two ahead of the other. By changing one controller a differential ratio between the two results, so that various speeds may be obtained. A fine speed adjustment is necessary to synchronize the motor speed with the natural time period of the raising and falling of the tools, in order to utilize the rebound of the tools in raising them. The maximum horsepower and speed of both motors is required for pulling the casing or hoisting the tools. When hard spots deflect the drill, resulting in a curved hole, the maximum torque of the motor is required to raise and drop the casing in the effort to get it past the curvature.

Rotary Drilling: In rotary drilling a drill is used consisting of a hollow spindle with a cutting tool at the lower end. Mud is pumped down the spindle and is forced up around the drill, lifting the material cut. The controller requires a wide speed range but the adjustment need not be as accurate as for cable drilling.

Advantages of Electric Drive for Oil Wells:

(1) ease of installation;
(2) continuity of service;
(3) relatively low cost of power;
(4) absence of standby losses;
(5) close and accurate speed adjustment;
(6) greater speed for cleaning and pulling;
(7) complete control is available from headache posts;
(8) safety to persons;
(9) low maintenance cost.

Electric power when available is of assistance in laying the pipe lines, as the joints may be welded when laid, dispensing with screw joints.

CHAPTER XXXVII

INDUSTRIAL AND MINE LOCOMOTIVES

Mine locomotives—locomotives in industrial establishments—trolley type for main haulage—trolley type for gathering service—tandem locomotive—storage battery locomotive—combined storage battery and trolley type.

The electric locomotive is a very important means of conserving the man power in our mines and industrial establishments. One man with a mule can handle a very small tonnage per day, compared with that which the same man can haul using an electric locomotive. Although the extra cost of the electrical equipment is considerable, it can usually be recovered in a short time where the tonnage is sufficient. The electric locomotive not only reduces the expense of hauling, but increases the efficiency of a mine or industrial establishment by the speed with which coal or finished material can be moved out of the way of workmen and new material brought to them.

When coal mining operations extended only a few hundred feet, the coal cars were hauled out to the shaft, or entry, by mules. As a mine was extended, gasoline engines and afterwards compressed air locomotives were tried. The most recent development is the use of electric locomotives, both for the main haulage and for gathering purposes. During the last few years rapid strides have been made in substituting electric locomotives for mules where any considerable tonnage is taken out.

A similar development has taken place in industrial establishments. Formerly, the material was trucked from one place to another by man power. This is being rapidly superseded by the automobile truck and storage battery locomotives.

At first the mining operations were taken care of by one type of locomotive, which was used for hauling the cars through the main tunnel. As the development of the mines progressed, and larger areas were worked, a new class of locomotive was designed for gathering the cars from the side rooms. Larger and more powerful haulage locomotives were then built which increased the size of the control apparatus and in many cases, the manual controller has been superseded by remote control.

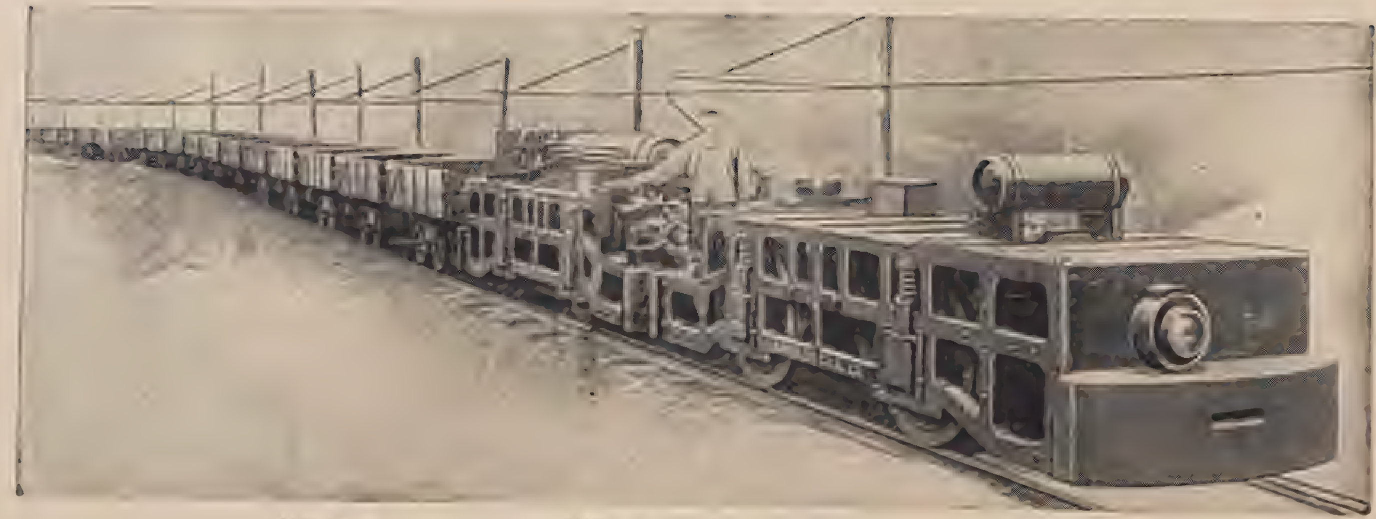


Fig. 423. 30-Ton Tandem Mine Locomotive Made up of Two 15-Ton Units

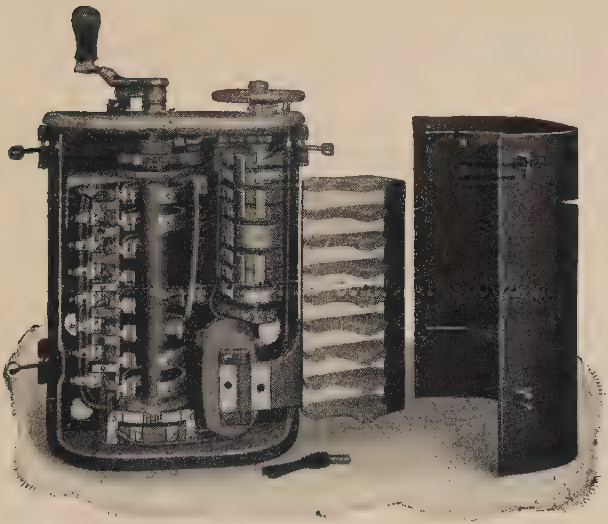


FIG. 426. Drum Controller

Showing separate drum for reversing and series or parallel connections

Electric locomotives for mine and industrial service may be divided as follows:

1. Trolley type locomotives for main haulage.
2. Trolley type locomotives for gathering service.
3. Storage battery locomotives.
4. Combined storage battery and trolley locomotives.

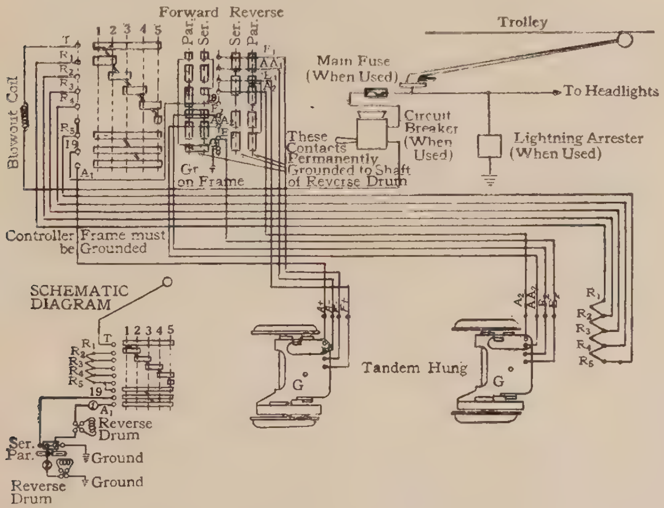


FIG. 427. Diagram of Drum Controller Shown in Fig. 426

The trolley locomotive is particularly well adapted for high speed, long hauls and heavy grades. It may employ a single trolley wire or third rail and use a bonded track for the return circuit. The single trolley is the usual practice in mines. In some industrial establishments, a double trolley or double third rail is used, in which case the track is not used to form part of the electric circuit and need not be bonded.

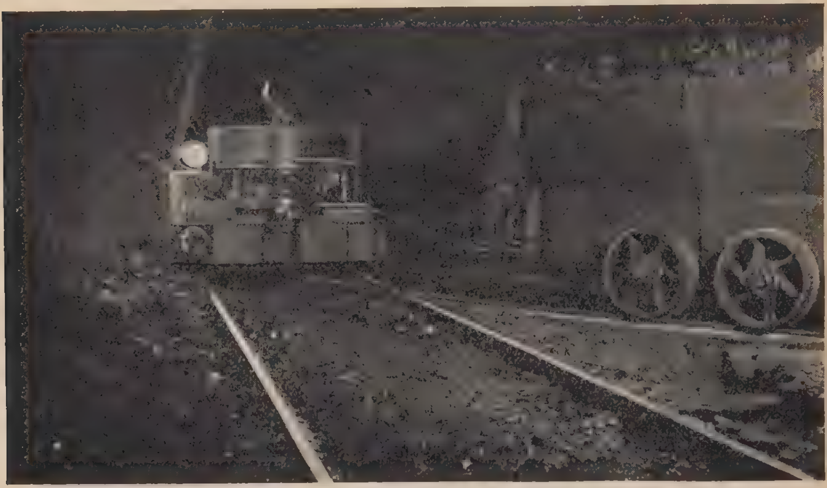


Fig. 428. Traction Reel Gathering Locomotive

The trolley locomotive for gathering service is employed only in mining operations. In addition to the usual locomotive equipment it may have a traction reel or a cable reel. The traction reel gathering locomotive is equipped with a motor-driven reel on which is wound a steel cable. The locomotive remains on the main haulage track and the cable

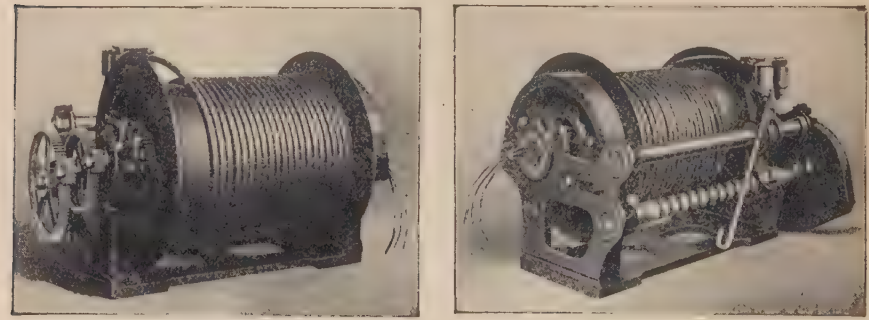


Fig. 429. Motor-operated Conductor Cable Reel

extends into the room or entry and is connected to the cars. The motor operating the reel draws the cars out to the main track so that the locomotive can couple to them. The reel motor is controlled by a simple rheostatic reversing drum controller.

Where the gathering reel is of the conductor cable type, Fig. 429, it may be mechanically driven from the axle or equipped with an individual motor. The conductor cable enables the locomotive to run on a room track for hauling the cars to and from the room working face. Where the electric cable is single conductor, the room track must be bonded. In many cases double conductor cable is used to avoid bonding these tracks. Where the reel is motor driven, an electric motor is built inside of the reel drum and is self-contained with the reel. The motor is connected across the power lines with a resistance in series. As the cable is wound off the reel, the motor is driven against its torque and keeps the cable taut. As the locomotive returns, the motor winds the cable on the reel. The action of the motor is thus equivalent to a spring. The torque, however, remains constant and does not vary as in the case of a mechanical spring. The cable passes through a guide driven by the

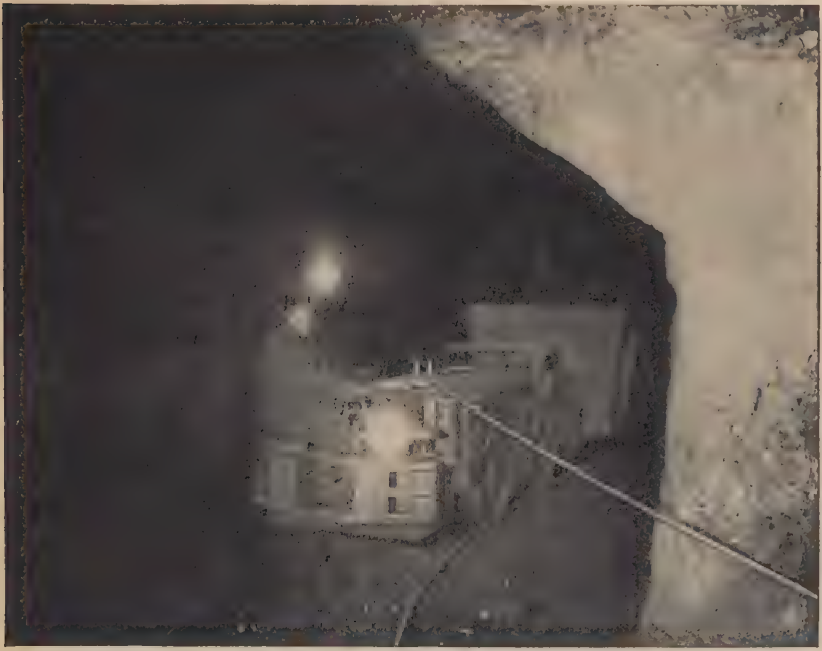


FIG. 430. Conductor Cable Reel Locomotive

reel which moves back and forth and causes it to wind uniformly across the face of the reel. Fig. 431 shows a diagram of electrical connections for the motor-driven reel and its control circuit.

The controllers used on all but the very large locomotives are manually operated, usually the drum type. Each controller is provided with two handles—the operating handle controls the speed of the locomotive; the other handle makes the proper connections for forward or reverse operation, and where two or more motors are used, it provides for either series or parallel connections. The handles are interlocked so that the direction of rotation and series or parallel connections cannot be changed unless the operating handle is in the off position. Controllers for mine locomotives must be made short in the vertical direction and as flat as possible, as the overall dimensions of the locomotive are very limited in mining work. Controllers for industrial locomotives need not meet these requirements.

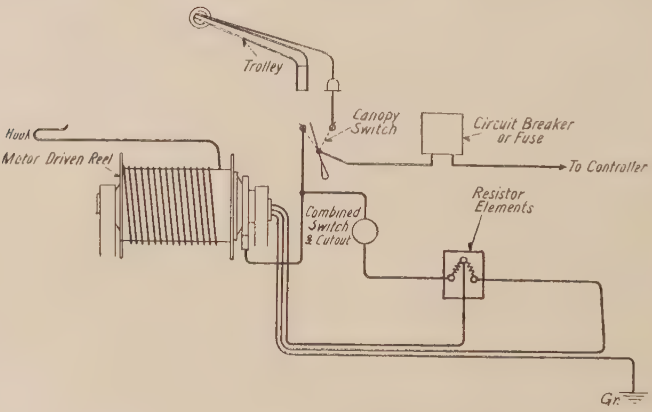


FIG. 431. Diagram of Motor-operated Conductor Cable Reel

Each locomotive usually has two or more motors which can be connected in series or in parallel. Fig. 427 shows the diagram of connections for a drum controller arranged for two motors. The drum connected to the operating handle is shown at the left of the main diagram and at the top of the schematic diagram. It connects the motors to the trolley circuit through a resistance which is short-circuited in five steps. To the right is the forward, reverse and series-parallel drum. These connections can be changed only when the drum shown on the left is in the off position, the interlock consisting of a mechanical connection between the handles on the inside of the controller.

Larger locomotives are equipped with air brakes and contactor control. The operating handle provides for both series and parallel connections. A separate handle sets the circuit for either forward or reverse operation. Fig. 432 illustrates a typical controller for this type arranged for two motors. These locomotives are sometimes quite large and are often used for handling several freight cars at one time.

SEOUENCE OF CONTACTORS

Step	LS_1	LS_2	R_1	R_2	R_3	R_4	R_5		P	S	G
1	O		O							O	
2	O	O	O							O	
3	O	O	O	O						O	
4	O	O		O	O					O	
5	O	O	O	O	O					O	
6	O	O	O	O	O	O	O			O	
	O	O		O						O	O
7	O	O		O					O		O
8	O	O		O	O				O		O
9	O	O	O	O	O				O		O
10	O	O	O		O	O			O		O
11	O	O	O	O	O	O	O		O		O

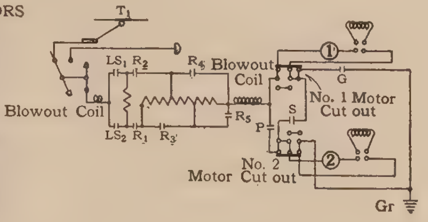


FIG. 432. Diagram of Contactor Control

A pusher locomotive differs from the regular locomotive by the addition of a bar which projects from the side of the locomotive and enables it to move the cars on an adjacent track, as illustrated in Fig. 433.

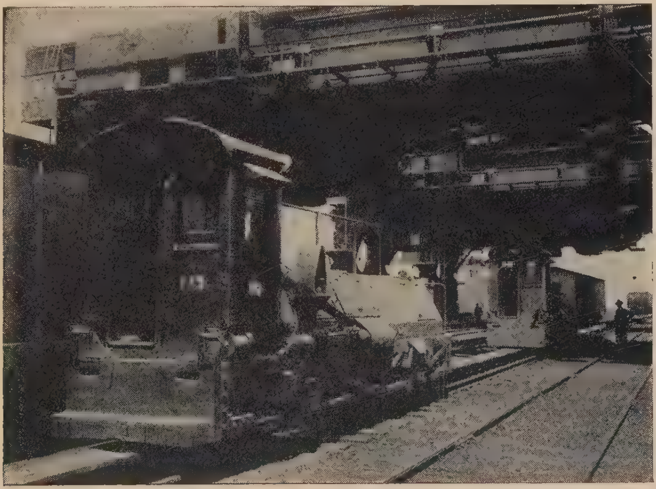


FIG. 433. Pusher Type Locomotive with Third Rail

On the Cleveland Ore Dock of the Pennsylvania Lines. This locomotive runs on tracks parallel to those of the cars, and pushes the cars with a pneumatically operated arm

It is often difficult for a locomotive operator to "spot" cars properly where the train is of any considerable length. It is possible to improve these conditions, by erecting a tower adjacent to the track and arranging the control so that the locomotive operator can leave the cab and operate his locomotive from the tower. Contactor control with master switches are used and a control wire is run from the locomotive to the tower by means of an additional trolley or third rail.

Where a considerable tractive effort is required and the size of rail or operating conditions will not permit the use of a single locomotive, the locomotive is divided into two parts and is known as a tandem locomotive, Fig. 434. One of the units is a leading or primary unit and the other a secondary unit. The primary unit is equipped with a four-motor controller to control two motors on each unit. The electrical connections between the two units are made with jumpers, each locomotive being equipped with its own resistor. The two units are operated electrically in parallel, the motors on each unit being connected in series or in parallel in the customary way, and the resistors on the two units being paralleled step to step by the controller contacts on both the series and parallel connections of the motors. When operated separately the connections on the primary unit which are provided for the motors and resistor of the second unit remain idle.

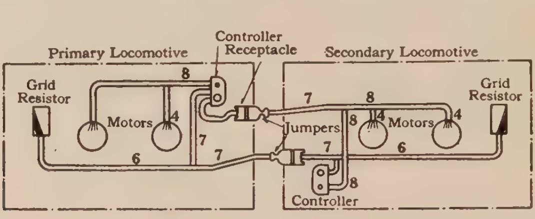


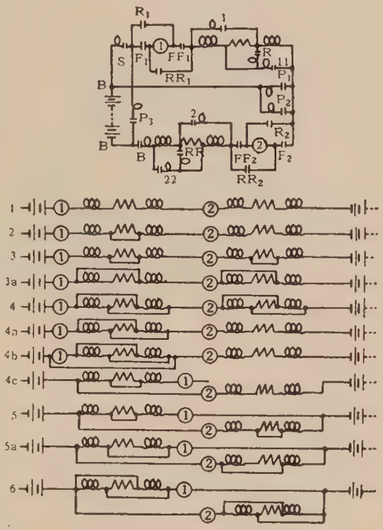
Fig. 434. Arrangement of Bus Line Receptacles for Tandem Locomotive

Fig. 435. Storage Battery Locomotives in an Industrial Plant

Where the locomotive is equipped with air brakes and remote control, arrangement can be made for connecting several of these units together and operating as a single locomotive. A good illustration of this is three 25-ton locomotives recently installed by a large copper company.

Each of these locomotives can be operated as a single unit or the three units can be connected together, giving the equivalent of a 75-ton locomotive with a distributed weight, so that no heavier track is required than for the single 25-ton unit.

Storage battery locomotives, Figs. 435 and 436, are usually designed for slow speeds of about 3.5 miles an hour. They are particularly adapted for short hauls and intermittent service. Heavy grades and high speeds cause a very high discharge rate on the battery, which makes the size of the battery out of proportion to the service rendered. These locomotives are operated in shifts to allow time for charging the battery. Sometimes extra batteries are provided to keep the locomotives in continuous service, the idle battery being charged while the other battery is in service on the locomotive. Storage battery locomotives are particularly well adapted for industrial purposes where a trolley wire or third rail would be objectionable. The loading and unloading of cars consumes time and a great deal of the work consists in shifting cars from one place to another, and in most industrial plants few if any grades are encountered. These locomotives are also well adapted for gathering service in mines. The volts per cell for commercial storage batteries is quite low so that motors are wound for considerably less voltage than is common for power service. This increases the current per horsepower considerably and makes it necessary to use larger contacts for a given horsepower. For a single motor, the controller consists of an ordinary drum with rheostatic control. The forward and reverse connections are made on a separate drum, the change in connections being made when the operating handle is in the off position.



SEQUENCE OF CONTACTORS

Step	Main Drum											Reverse Drum							
												Forward				Reverse			
	S	B	R	R	1	11	2	22	P_1	P_2	P_3	F_1	FF_1	F_2	FF_2	R_1	RR_1	R_2	RR_2
1	○	○										○	○	○	○				
2	○	○	○									○	○	○	○				
3	○	○	○	○								○	○	○	○				
3a	○	○	○	○	○		○					○	○	○	○				
3b	○	○			○		○					○	○	○	○				
4	○	○			○	○	○	○				○	○	○	○				
4a	○	○			○	○						○	○	○	○				
4b	○	○			○	○			○	○		○	○	○	○				
4c		○	○						○	○		○	○	○	○				
5		○	○	○					○	○	○	○	○	○	○				
5a		○	○	○	○		○		○	○	○	○	○	○	○				
5b		○			○		○		○	○	○	○	○	○	○				
6		○			○	○	○	○	○	○	○	○	○	○	○				

FIG. 436. Diagram of a Two-motor Storage Battery Control

Where two or more motors are used, the motor armatures and fields are combined in series and parallel relations which gives a wide range of speed with very little rheostatic loss and conserves the energy in the storage battery. Fig. 436 is a schematic diagram showing such an arrangement. The numerals *1* and *2* represent the two motors. Each motor is provided with a double field winding. The motors are first connected with their armatures and all of their field windings in series. This gives a maximum field strength and maximum torque with a relatively small current. After the starting resistance has been short-circuited, the field windings are connected in parallel, giving a higher

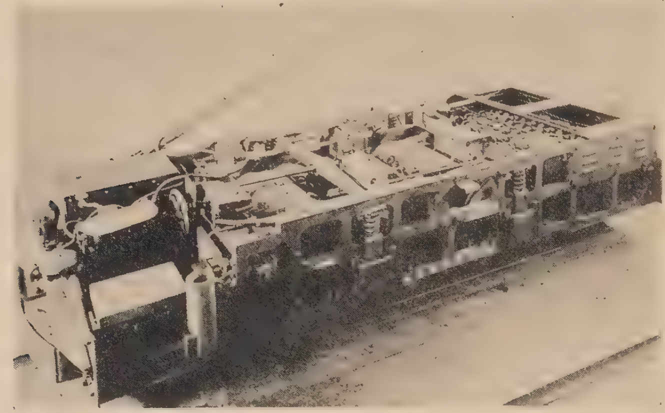


Fig. 437. Combined Trolley and Storage Battery Locomotive

With cover removed showing location of the motors and storage battery

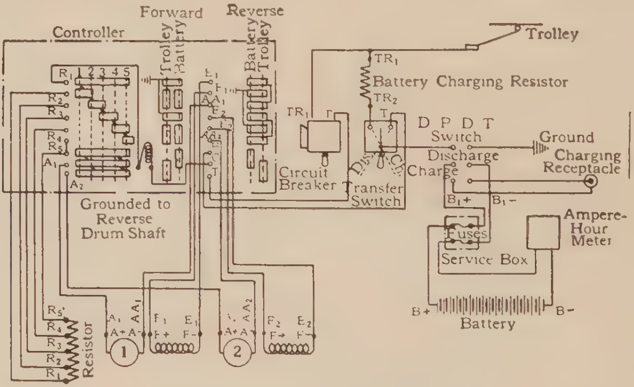


Fig. 438. Diagram of Controller for Combined Trolley and Storage Battery Locomotive

speed by field control. Higher speeds are obtained by changing the armatures from series to parallel connections. Six operating speeds are shown on this diagram. The steps marked with sub letters, such as *3a, 4a,* etc., are transition steps and not intended for running positions.

Sometimes, the locomotive is designed for operation both from a storage battery and a trolley, the battery being used for short hauls where it is not convenient to provide the trolley wire, such as for gathering purposes in a mine. Fig. 437 shows such a locomotive and Fig. 438 a diagram of connections. The operating handle provides ordinary rheostatic control. The separate handle which can be moved only when the operating drum is in the off position provides for connections for either forward or reverse operation on either the trolley or battery. A locomotive of this kind has considerable flexibility, but the added weight of the battery is a disadvantage in operating on the trolley wire. Some quite large industrial locomotives of this kind are employed by a large plant where it is necessary to haul cars across property where a trolley cannot be installed. In such cases, the battery can be charged, if desired, while the locomotive is operating from the trolley.

SUMMARY OF CHAPTER XXXVII

Coal was formerly hauled from mines in cars drawn by mules. The latter were replaced by gasoline engines, later by compressed air locomotives, and more recently by electric locomotives. While the electrical equipment is expensive, more work can be done by the operators, resulting in savings, in mines where the tonnage is sufficient, that soon pay for the equipment.

Mine and industrial establishment locomotives may be classified as follows:

(1) trolley type locomotives for main haulage;
(2) trolley type locomotives for gathering service;
(3) storage battery locomotives;
(4) combined storage battery and trolley locomotives.

The trolley locomotive is adapted to high speeds, long hauls, and heavy grades. A single trolley wire or third rail may be used and the rails bonded, or, to avoid bonding, a double trolley wire or double third rail may be employed. In gathering service in mines, cars are drawn by a cable from side rooms to the main tunnel, for attaching to the gathering locomotive, the cable being wound by a motor-driven traction reel with which the locomotive is equipped; or the traction reel may be replaced by a cable reel, motor driven or driven mechanically from the locomotive axle, the cable in this case consisting of a conductor enabling the locomotive to go to the side rooms for cars.

The locomotives usually have two motors, which may be connected in series or in parallel. Generally a drum controller is provided, with two handles, one for accelerating and the other for reversing. A pusher locomotive has a bar projecting at the side, enabling it to move cars on adjacent tracks. When the spotting of trains is difficult, provision is sometimes made for the operator to leave the train and operate it from a control tower.

When, to obtain added tractive effort, it would be necessary to use locomotives heavier than the tracks are intended for, a tandem locomotive, divided into two parts, a primary and a secondary unit, is used. The units are operated in parallel, the motors in each unit being connected in series or in parallel, or, the primary unit alone may be operated. With an air braking system and remote control, three 25-ton locomotives, for example, may be operated in tandem, giving the equivalent of a 75-ton locomotive, with its weight distributed on tracks of only 25-ton capacity.

Storage battery locomotives are equipped with motors designed for a low voltage, operated from storage batteries, and are adapted for short hauls and intermittent service over level tracks, at speeds of about 3½ miles per hour. A wider range of speed, with small resistance losses, and conservation of the battery, is obtained if two motors and series-parallel connections are used. Trolley locomotives are sometimes furnished with storage batteries, to permit operation over sections of track not supplied with trolley wires.

CHAPTER XXXVIII

ELECTRIC LOCOMOTIVES FOR HEAVY TRACTION

Freight locomotives on trolley lines—electrification of steam railways—advantages of electric locomotives—tendency toward high voltages—how varied speeds are obtained—two distinct control problems—acceleration and regeneration—how saving results from electrification.

Electric locomotives are replacing steam locomotives in an increasing number of applications. In many places, in fact, where electric locomotives are now used, it would be impractical to use steam-driven machines.

Among the more important applications for the electric locomotives are the following:

Local Freight

Many trolley systems are using locomotives for hauling farm products from the suburban districts, for removing city refuse and for distributing materials of construction, such as are used in buildings, for the making of roads, and other similar work. During the night and also during portions of the day normal traffic is materially reduced so that electric locomotives can handle freight during these times to good advantage. This increases the revenue for the railway company with very little additional investment or operating expense. The lighter types of locomotives are used for this service. These locomotives may also be used for hauling material between different cities or towns where the railway company maintains interurban service.

Feeders for Main Line Railway

The electric locomotive can be used to good advantage on both urban and interurban lines and also on spur lines of main railways to haul freight to and from the main trunk line. Often a manufacturing establishment can be located outside the congested district of the city and away from the main line of the railway, where land is available at a reasonable price, and shipments can be made over existing trolley roads or the railway can run a spur track to the establishment. Service of this kind is called feeder service. Local freight haulage would include the handling of freight which originated on and was delivered over the local lines.

ELECTRIFICATION OF STEAM RAILWAYS

In this country the electrification of steam railways is taking place mainly in short sections. The locomotives are built for either passenger, freight or switching service.

The electrification of large terminals has proved very satisfactory, particularly in cities like New York and Philadelphia. When electrified, a much larger number of cars can be handled over the same tracks and the resulting absence of smoke and dirt is desirable and in many cases required by law. Better facilities for handling traffic enables the service to be improved and more people use this means of transportation so that traffic increases in proportion to increased facilities and greater revenue can be obtained without enlarging the size of the terminal. Notable examples of terminal electrification are the Pennsylvania Railway Terminal, the New York Central, and the New Haven Terminals all in New York, and the Pennsylvania Railway Terminal at Philadelphia. At the Philadelphia terminals and also at the Grand Central Station at New York, considerable time was once taken up in running engines out to a turn-table in order that they might be used to draw trains out of the terminal. This is avoided with the electric equipment which operated equally satisfactorily in either direction.

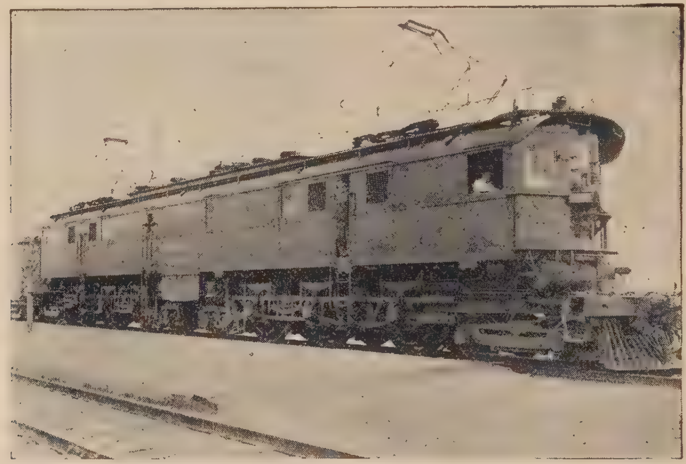


FIG. 439. 4200-Horspower Electric Locomotive Used for the Passenger Service on the Chicago, Milwaukee & St. Paul Railroad

Tunnels form another section of the railway which gives room for a decided advantage from electrification. The smoke and gases from steam locomotives are very difficult to take care of in a tunnel and they are very annoying to passengers. In some of the terminal electrifications, particularly those around New York, it is necessary to use tunnels and this was another cogent reason for electrifying the terminals. The elimination of the smoke and gases from the locomotive in these tunnels was a great improvement from the passenger's standpoint and contributed more than any other one cause to an increased use of the steam roads by passengers in the electrified area.

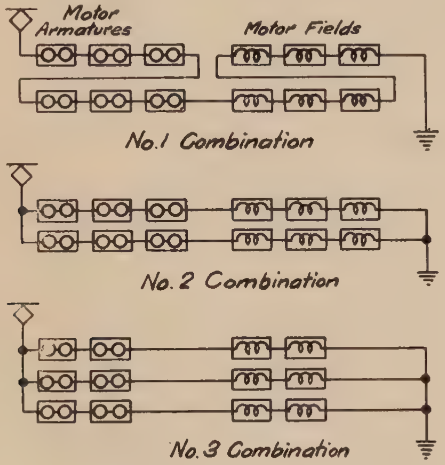


FIG. 440. Series-parallel Connection for Motoring

Examples of electric traction in tunnels used principally for freight purposes are the St. Claire Tunnel, Hoosac Tunnel, and the Cascade Tunnel. These are all long tunnels and the moving of freight over a large section of the road was speeded up by electrification. Freedom from smoke and gases made it easier for the train crew to operate trains, also the electric locomotive moved the train more rapidly and at a more uniform speed than could the steam locomotives.

The electric locomotive is particularly well adapted for switching in and about industrial plants within the city limits. The use of a steam locomotive for this purpose is disagreeable and in many cases prohibited by law.

ADVANTAGES OF ELECTRIC TRACTION

1. The electric locomotive increases track capacity as it is not necessary to make stops for coal or water. On this account the locomotive is useful for hauling trains continuously.

2. Flexibility. Two or more locomotives can be coupled together and readily operated as a single unit. For long trains one set of units can be used at the head and the other as a pusher. The ease and reliability of control under these conditions makes it possible to handle larger train units at a higher average speed.

3. The size of the train is limited only by the draw bar strength. The speed is limited only by grades, curves, and track construction. By using the required number of electric locomotives a long train can be operated as rapidly as a short one.

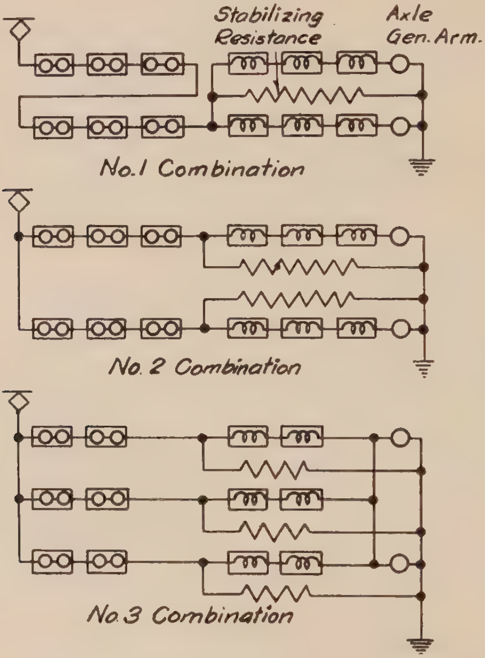


FIG. 441. Series-parallel Connections for Regenerating

4. The electric locomotive may be operated in either direction for terminal service or short hauls, avoiding the time lost in turning a steam locomotive.

5. Availability of service. The electric locomotive has no boiler or grates to clean and does not require water and has no fire to light or bank. It does not generate its own power but receives it from the power plant and is therefore always ready for service and the length of the run is not limited.

6. The electric locomotive develops its rated speed and torque in cold weather as well as warm weather. In cold weather the steam loco-

motive has less steaming capacity and therefore develops less horsepower. Cold affects the track resistance and frost or ice may decrease the tractive effect so that it is more difficult to handle trains in cold weather than warm weather with either locomotive, but the steam locomotive had the added disadvantage of reduced output in cold weather while the electric locomotive has an increased continuous capacity due to the cooler air temperature.

TABLE IX

MOTOR COMBINATIONS

Motor Combination Number	Motor Grouping	Speed	Voltage per Commutator
1	All six in series	One-third	250
2	Two parallel sets of three motors in series	Two-thirds	500
3	Three parallel sets of two motors in series	Full	750

7. Greater division lengths may be used. The length of a division on a railroad is fixed largely by the distance a steam locomotive can operate without being withdrawn from service for a short length of time. The electric locomotive may continue on almost indefinitely so that it is capable of hauling trains continuously for long distances and is only limited by the durability of freight cars.

POWER

Electric locomotives may be supplied with either direct-current or alternating-current power. Direct-current power is distributed at 600, 1500 or 3000 volts. A-c. power is usually distributed at 11,000 volts, 25 cycles. The tendency in both d-c. and a-c. is toward higher voltages. The introduction of 3000-volt direct current in this country has been comparatively recent.

When direct current is used the locomotive is driven by series-wound motors. These motors may be provided with a shunt for weakening the field to give normal operating speeds. The advantage of using field weakening is that an extra heavy field is available at the time of starting and can be used for short time operation where a slow speed is desired. A series-wound motor is preferable to one compound or shunt wound for this class of service as the commutation is better when the motor is subjected to sudden changes in load or voltage.

When the source of power is alternating current the locomotive may be driven by a commutator motor or an induction motor. The commutator type of motor gives substantially the same range of speed control as is obtained with direct current. It can also be used on direct-current circuits where the locomotive has to operate over a right of way using direct-current power. An instance of this is the New Haven electrification, operating over a portion of the New York Central lines at the terminal of the latter at New York.

The induction motor is essentially a constant-speed machine and is particularly well adapted for freight service. Different operating speeds can be obtained by changing the number of poles on individual motors or by operating two motors in cascade. The Norfolk and Western Electrification is an illustration of induction motor-driven locomotives.

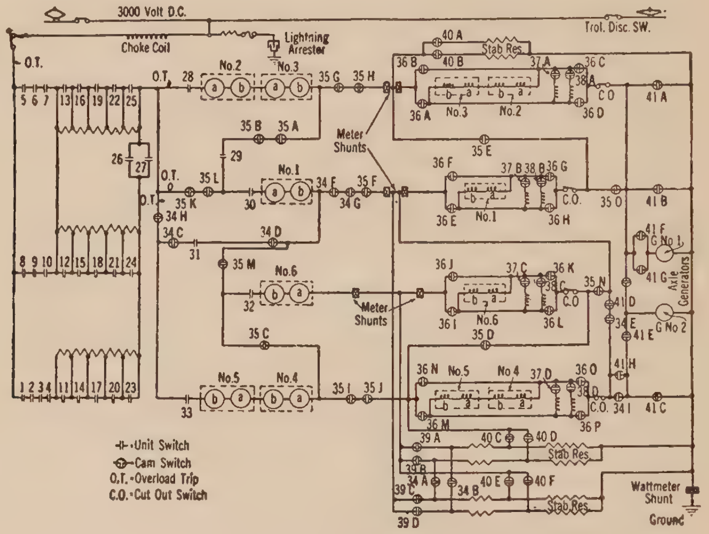
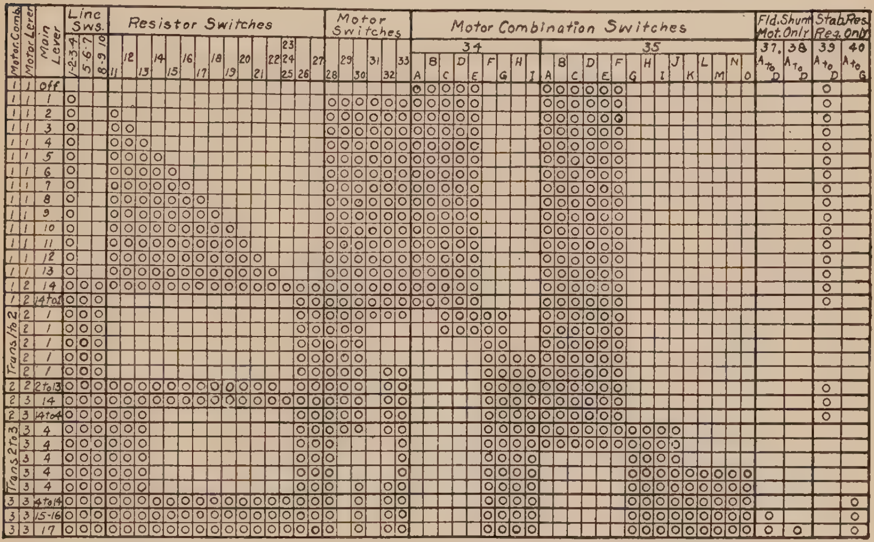


FIG. 442. Schematic Diagram of Main Motor Circuits

CONTROL

The function of an electric locomotive is to propel a train either on the level or up hill by taking power from the line and to hold the train back in going down hill by returning power to the line. In addition to these primary functions the locomotive may be required to provide lighting for a passenger train or to heat the train.

There are two distinct controller problems involved in locomotive design. One has to do with acceleration and the other with regeneration. In both cases it is desirable to have several operating speeds to meet the different service requirements. The operating speeds are obtained by connecting commutator motors in series and parallel groupings, or if a-c. induction motors are used they may be grouped in cascade with different pole combinations. If a locomotive is equipped with two series-wound motors two operating speeds can be obtained, four motors will give three operating speeds. The more pairs of motors used the greater the selection of speeds. Induction motors may give two speeds, one in cascade, and one in parallel, or each induction motor may have two sets of poles so that three operating speeds are obtained.



Motor Comb.	Motor Lever	Main Lever	Line Sws.			Resistor Switches															Motor Switches						Motor Combination Switches																								Fld. Shunt Mot. Only		Stab. Res. Reg. Only	
			1-2-3-4	5-6-7	8-9-10	11	12	13	14	15	16	17	18	19	20	21	22	23 24 25	26	27	28	29	30	31	32	33	34									35															37	38	39	40
																											A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	A to D	A to D	A to D	A to G
1	1	Off																									○	○	○	○	○					○	○	○	○	○	○												○	
1	1	1	○																		○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	2	○			○															○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	3	○			○	○														○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	4	○			○	○	○													○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	5	○			○	○	○	○												○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	6	○			○	○	○	○	○											○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	7	○			○	○	○	○	○	○										○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	8	○			○	○	○	○	○	○	○									○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	9	○			○	○	○	○	○	○	○	○								○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	10	○			○	○	○	○	○	○	○	○	○							○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	11	○			○	○	○	○	○	○	○	○	○	○						○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	12	○			○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	1	13	○			○	○	○	○	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	2	14	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
1	2	14 to 1	○	○	○														○	○	○	○	○	○	○	○	○	○	○	○	○					○	○	○	○	○	○												○	
Trans 1 to 2	2	1	○	○	○														○	○	○	○	○	○	○	○			○	○	○	○	○			○	○	○	○	○	○													
	2	1	○	○	○														○	○	○	○	○						○	○	○	○	○			○	○	○	○	○	○													
	2	1	○	○	○														○	○	○	○	○									○	○			○	○	○	○	○	○													
	2	1	○	○	○														○	○	○	○	○									○	○	○	○	○	○	○	○	○	○													
	2	1	○	○	○														○	○	○	○	○		○	○						○	○	○	○	○	○	○	○	○	○													
2	2	2 to 13	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○		○	○						○	○	○	○	○	○	○	○	○	○												○	
2	3	14	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○						○	○	○	○	○	○	○	○	○	○												○	
2	3	14 to 4	○	○	○	○	○	○											○	○	○	○	○		○	○						○	○	○	○	○	○	○	○	○	○												○	
Trans 2 to 3	3	4	○	○	○	○	○	○											○	○	○	○	○		○	○						○	○	○	○	○	○	○	○	○	○	○	○	○	○									
	3	4	○	○	○	○	○	○											○	○	○					○						○	○	○	○	○	○	○	○	○	○	○	○	○	○									
	3	4	○	○	○	○	○	○											○	○	○					○						○	○	○	○							○	○	○	○									
	3	4	○	○	○	○	○	○											○	○	○					○						○	○	○	○							○	○	○	○	○	○	○	○	○				
	3	4	○	○	○	○	○	○											○	○	○		○		○	○						○	○	○	○							○	○	○	○	○	○	○	○	○				
3	3	4 to 14	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○						○	○	○	○							○	○	○	○	○	○	○	○	○				○
3	3	15-16	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○						○	○	○	○							○	○	○	○	○	○	○	○	○	○			○
3	3	17	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○						○	○	○	○							○	○	○	○	○	○	○	○	○	○	○		○

FIG. 443. Sequence of Switches in Main Motor Circuits

In controlling d-c. series motors the shunt method of transition is the one commonly used. Automatic acceleration is impracticable on account of the different loads under which the locomotive is started and the different grades on which it operates. Bridging transition, to give the best results, requires automatic acceleration and uniform loading.

The problem in series-parallel control of locomotives is to obtain a uniform change in torque during both acceleration and regeneration. In starting up, the slack must be taken out of the couplings before any large amount of tractive effect is developed. When the train is slowed down on a hill, by notching back on the controller the locomotive may rapidly decelerate taking up the slack and then jerking it out again as it exerts tractive effort at the new speed. The ideal arrangement would be a controller that gave equal increments of speed change when accelerating or decelerating under all conditions of loading. Such an arrangement is impractical to obtain when the locomotive is provided with rheostatic control so that great care must be exercised in proportioning the controller and adjusting each of the notches to give the best average results.

General

In order to obtain a better understanding of locomotive practice a number of diagrams and illustrations are shown of existing installations in the United States. European practice differs in some respects from that in this country.

The experience which is being gained is enabling engineers to improve the electric locomotive and overcome some of the difficulties that developed in practice.

A great deal has been written on this subject and many interesting articles have appeared in the technical press. Undoubtedly the electric locomotive has proved a solution to many of the railway problems, particularly those that have to do with terminals, tunnels and relatively short sections of track which limited the hauling capacity of the entire system. Electrification will continue to be applied to the parts of a railway system where of greatest advantage, and then probably extended so that one electrified section will be linked up with the next until whole divisions of a trunk line will be electrified. This has already occurred on a large portion of the Chicago, Milwaukee & St. Paul Railroad.

It has been stated that one-sixth of all the coal hauled by our railroads is used by them for fuel. In the west where coal is scarce, oil is used as a fuel. When we consider the great burden imposed on our railways caused by hauling their own fuel, it can be readily seen that the utilization of water power or the location of central stations in coal mining districts from which power is transmitted to electric locomotives, will materially increase the revenue tonnage of the railroad by relieving it of the coal formerly hauled for its own locomotives and by increasing the weight of the trains and the average speed with which they are moved. Mr. A. H. Babcock, in a paper on "An Unusual Railway Electrification" gives the results of the electrification of the Elkhorn grade of the Norfolk & Western Railway. He states that immediately prior to electrification the average trains per month were 290, and the average tonnage per month 852,750. Soon after electrification the average trains per month had increased to 412 and the average tonnage 1,141,402.

The total amount of freight handled over existing systems can be very materially increased by proper electrification without increasing track mileage. The competition of the electric locomotive has stimulated the designers of steam locomotives to greater efforts and material improvements have recently been made in the performance of steam locomotives. This is a very healthy result and while it may retard the complete electrification of many railway systems it is benefiting the community at large and the credit for this improvement is due the Electrical Engineer.

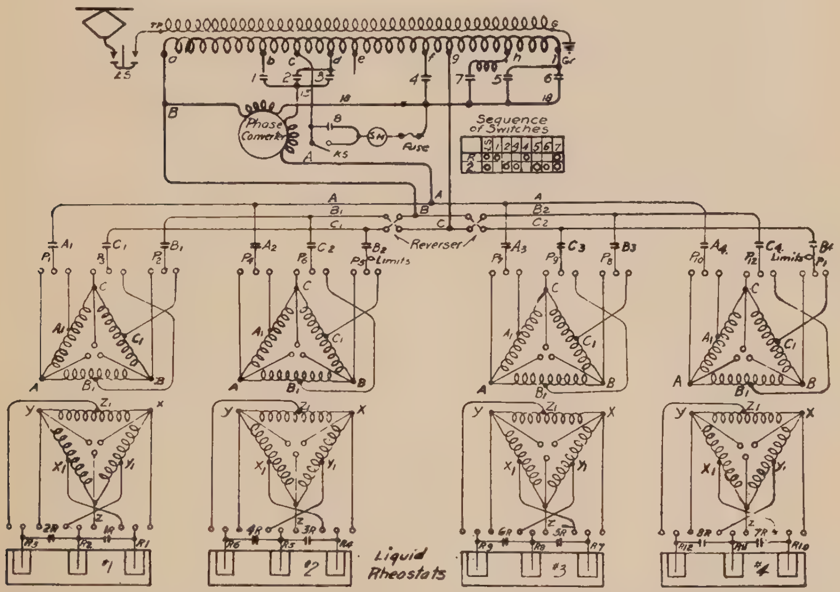


FIG. 444. Schematic Diagram of Main Circuits, Single-phase Locomotive, Induction Motor Type

SUMMARY OF CHAPTER XXXVIII

Light electric locomotives are frequently used on trolley lines, during the night and parts of the day when the regular traffic is light, to haul local freight, such as farm products, building and road construction material, etc.

The electrification of steam railways is usually begun at points where electric locomotives may be used most advantageously, as for example:

(1) in feeder service, or over spur lines from manufacturing plants to main trunk lines;
(2) at terminals in large cities, where it is desired to handle more traffic without increasing the size of the terminal;
(3) through tunnels in cities, where smoke and cinders are objectionable, or are prohibited by law;
(4) over short sections of track which limit the hauling capacity of the entire system;

(5) for switching service in and about industrial establishments.

Electric locomotives, when compared with steam locomotives, have the following advantages:

(1) stops for coal and water are eliminated;
(2) two or more locomotives are easily coupled together and operated as a unit; hence,
(3) the size of a train is limited only by its draw bar strength, the speed of trains is limited only by grades, curves, and track construction;
(4) since electric locomotives operate equally well in either direction, turntables and time lost in turning are eliminated;
(5) the locomotives are always ready for service: the length of runs is not limited;
(6) their greatest continuous capacity is available in cold weather, at the time most needed, when the steam locomotive has its least power;
(7) the length of railway divisions may be indefinitely extended.

In railway work the tendency is toward high voltages. Direct-current voltages of 600, 1500, and 3000, and an a-c. voltage of 11,000 (25 cycles), are at present used. Direct-current locomotives are driven by series-wound motors, the commutation of which is better under sudden changes in load or voltage. For a-c. lines induction motors may be used, or, where operation is necessary over both a-c. and d-c. lines, commutator motors are employed. To obtain the number of speeds required, commutator motors are connected in series and in parallel, and induction motors are connected in cascade, with different pole combinations. Two speeds are obtainable from locomotives equipped with two series motors, three from those equipped with four motors.

As locomotives must propel the train up grade or on the level and hold it back on down grades, two distinct control problems are presented, one of acceleration and the other of regeneration. The chief problem in series-parallel control is to obtain a uniform change in torque during acceleration and regeneration. In going down hill, for instance, notching back the controller retards the locomotive and takes up the slack in the couplings, only to jerk back when the wheels resume tractive effort at the new speed. Great care is therefore necessary in proportioning the controller and adjusting the speed notches for the best average results. With direct-current motors, shunt transition is commonly used. Automatic acceleration is impracticable on account of the different load conditions encountered. Good results are obtainable from bridging transition only where the load is uniform and automatic acceleration may be used.

It is estimated that one-sixth of the coal hauled by the railroads is required by them as fuel. In the west where coal is scarce and the oil supply insufficient, electrification saves coal, permits hauls of greater weight, greater speed of trains, and hence increases the total freight carried without increasing the track mileage. An indirect result of electrification has been the improvement of the steam locomotive, due to competition.

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